5 LIMITING FACTORS AFFECTING LAKE OZETTE SOCKEYE

Many of the limiting factors described in this chapter were first identified during preliminary work by the Lake Ozette Sockeye Steering Committee in 1999 and 2000. The concepts presented here are a continuation of these initial efforts and are based upon direction given by committee stakeholders in the summer of 2004. The limiting factors affecting the productivity and survival of Lake Ozette sockeye have been previously investigated and documented in detail in several reports and studies (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; Gustafson et al. 1997). Chapter 5 updates previous work and incorporates recent research in an effort to provide a complete description of the best available information regarding limiting factors affecting Ozette sockeye salmon productivity and abundance.

5.1 METHODS AND FRAMEWORK

Limiting factors affecting Lake Ozette sockeye are identified by geographic area in Sections 5.2 through 5.6. Geographic areas assessed for limiting factors are the following:

- Estuary and Nearshore Environment (Section 5.2)
- Ozette River (Section 5.3)
- Lake Ozette (Section 5.4)
- Lake Ozette Tributaries (Section 5.5)
- Off-Shore Marine Environment (Section 5.6)

All limiting factors that may affect Lake Ozette sockeye are assessed and included within Sections 5.2 through 5.6.2. Several limiting factors that are unlikely to significantly decrease Lake Ozette sockeye productivity and/or viability are also included for completeness, and to illustrate the exhaustive nature of the review of potential or perceived limiting factors. In the following subsections, limiting factors are presented by geographic area and then further described by the sockeye life history stage affected within each geographic area. The degree to which a potential limiting factor is likely to limit sockeye productivity is also discussed by life stage, within each geographic area. Processes and/or actions influencing several of the limiting factors are discussed following the introduction of each limiting factor.

A qualitative rating for each of the limiting factors affecting sockeye salmon survival and productivity by sub-population and life stage is included in Chapter 6.

5.2 ESTUARY AND NEARSHORE ENVIRONMENT

Lake Ozette sockeye occupy the small Ozette River estuary and the nearshore environment of the Pacific Coast during their smolt emigration period, as well as during their adult migration into the Ozette River (see Sections 3.1.1, 3.1.9, 3.1.10). These two life history phases in these environments are the focus of this section. Tidal prism and estuarine habitat conditions (see Section 4.1), predation, direct harvest, and nearshore ocean productivity (see Section 4.1) are all factors that currently or in the past have limited sockeye salmon survival and productivity.

5.2.1 Tidal Prism and Physical Estuarine Habitat Conditions

Changes in the tidal prism and estuarine habitat conditions appear to have occurred during the last 50 years. The cause of these apparent changes is poorly understood, as are the potential effects on Lake Ozette sockeye.

5.2.2 Predation

Predation on sockeye salmon in the Ozette River estuary and nearshore environment is not well documented. No data exist regarding smolt predation in the estuary or nearshore environment. It is suspected that juvenile sockeye are preyed upon during their migration through the estuary and nearshore, but the degree to which this occurs remains unknown. During the summer of 2000, a joint study was conducted by NOAA-National Marine Mammal Laboratory (NMML) and MFM investigating pinniped interactions with Lake Ozette sockeye. Adult sockeye entering the Ozette River were captured in the estuary using a trap. Sockeye were handled, examined for scarring, tagged, and then released. It was found that 32.9% (27/82) of the sockeye captured in the estuary had scars associated with predation events. Scars were classified as “new” or “old” based upon the freshness of the wound. Just over 77% of the scarred fish had scars that were classified as “old” and 52% had scars classified as “new.” Several of the sockeye captured had scars from multiple predation events resulting in scars classified as both “old” and “new.” Figure 5.1 depicts a sockeye that has predator associated scarring classified as both “old” and “new.”

Gearin et al. (2002) were unable to determine the location where the scarring events took place but speculated that the likely areas were (1) the estuary downstream of the trap, (2) just off-shore of the mouth where sockeye stage prior to entering the river, or (3) off-shore in the open ocean. Sockeye trapping conducted during the summer of 2000 provided further evidence of harbor seal (*Phoca vitulina*) and river otter (*Lutra canadensis*) predation in the Ozette River (Gearin et al. 2002). Gearin et al. (2002)) concluded that the predator scarring rate (32.9%) for fish in the lower river was exceptionally high. The amount of predation mortality was not quantified in observations conducted in the lower Ozette River during the 1998, 1999, and 2000 sockeye returns. In addition to direct predation mortalities, unsuccessful predation events resulting in open wounds and lesions in the lower river and nearshore environment likely decrease the fitness of adult sockeye and make them more susceptible to disease during the protracted lake holding period.

Figure 5.1. Sockeye captured in the Ozette River estuary with "old" arch marks and "new" bite marks (source: MFM photo archives).

5.2.2.1 Predators

5.2.2.1.1 Sea lions (Zalophus californianus; Eumetopias jubatus)

Pinniped-sockeye interactions observed in the Ozette watershed from 1998 through 2000 did not include observations of sea lions within the Ozette River or lake (Gearin et al. 2000). Gearin et al. (2000) found that 25% of the identifiable scars on sockeye captured in the lower river were from wounds inflicted by sea lions. Based on an examination of the inter-canine distances measured on scarred sockeye it was determined that 15% of the scars were associated with California sea lions (*Zalophus californianus*) or sub-adult Steller sea lions (*Eumetopias jubatus*) and that 10% of the scars were from adult Steller sea lions. Since sea lions have not been observed within the river, it is thought that nearly all sea lion predation occurs in the nearshore or open ocean. Steller sea lion and California sea lion population counts from May through August within 18.5 km of the Ozette River mouth ranged from 404 to 1,016, and 0 to 541 individuals, respectively (Gearin et al. 1999). Sea lion scat samples were collected in 1998 from within 11.5 miles (18.5 km) of the Ozette River, and salmonid remains were found in 9.6% (18/187) of the scats with identifiable prey items (Gearin et al 1999). Gearin et al. (1999) were unable to determine the salmonid species found in the sea lion scat samples examined.

5.2.2.1.2 Harbor Seals (Phoca vitulina)

A large population of harbor seals use the area near the mouth of the Ozette River. Harbor seal abundance within 5 km of the Ozette River mouth from May 5 to June 30, 1998 ranged from 950 to 1,393 (Gearin et al. 1999). Gearin et al. (2000) found that 60% of the identifiable scars on sockeye captured in the lower river were from wounds inflicted by harbor seals. Gearin et al. (1999) collected and examined 347 harbor seal scats from haul-outs within 3.4 miles (5.5 km) of the mouth of the Ozette River. (Only 330 scats contained identifiable prey.) Salmonids were found in only 1.5% of the samples collected and were identified as coho and Chinook; no sockeye remains were detected in any of the harbor seal scat samples examined. However, none of the harbor seal scat samples were collected from the Ozette River.

Harbor seal activity at the mouth of the Ozette River was systematically monitored during the spring and summer of 1998 (Gearin et al. 1999). During the period from June 3 to June 30, 1998, 1.3 individual seals per hour were observed in the river and off of the river's mouth; this period corresponds to the peak sockeye migration period for 1998. From July 1 through July 22, 1998, only 0.31 individual seals per hour were observed in the river and off of the river's mouth. Seal observations per hour were more than 4 times higher during the peak sockeye migration period (average daily entry estimated at 43 sockeye – see Haggerty 2005d) than the period just after peak migration when sockeye entry into Lake Ozette averaged just over 7 sockeye/day.

During pinniped monitoring in 1998, no direct predation events on sockeye were observed in the river or off of the river's mouth (Gearin et al. 1999). Additional monitoring in the lower river was conducted for 22 days in 1999. No predation on sockeye by harbor seals was observed in 1999 (Gearin et al. 2002). However, seals were frequently observed foraging in the lower river during monitoring from 1998 to 2000 (Gearin et al. 1999; Gearin et al. 2002). On June 9, 2000, harbor seals were observed killing 2 sockeye salmon. Gearin et al. (2002) were unable to quantify the number of sockeye salmon killed by harbor seals in the lower Ozette River. They concluded that part of the difficulty in deriving predation estimates is that visual observations are often limited to daylight hours and much of the predation appears to occur during darkness.

5.2.2.1.3 River Otters (Lutra canadensis)

River otters are quite common in the Ozette River; but no river otter population estimates exist. Gearin et al. (1999) describe the Ozette River as ideal river otter habitat. River otters are distributed throughout the entire length of the river. Predation monitoring during the sockeye run from 1998 through 2000 was conducted in the lower river. No direct observations of river otters killing sockeye salmon were made in the lower river and nearshore environment during the 3-year monitoring period (Gearin et al. 1999; Gearin et al. 2002).

5.2.2.1.4 Other Predators

The entire suite of predators that prey upon juvenile and adult sockeye salmon in the Ozette estuary and nearshore environment is unknown. It is likely that in addition to pinnipeds, several species of birds and fish also prey on Lake Ozette sockeye. On June 22, 2000, a bald eagle (*Haliaeetus leucocephalus*) was observed carrying and eating a large salmonid, most likely an adult sockeye, at the mouth of the Ozette River.

5.2.2.2 Factors Affecting Predation

5.2.2.2.1 Increases in pinniped abundance

The California sea lion population across its range (from Mexico to British Columbia) has increased dramatically during the last 60 years (NMFS 1997). Commercial harvest of California sea lions from the 1800s to 1940s had reduced their numbers, but the population gradually began to increase with the end of commercial hunting in the 1940s (NMFS 1997). Since the passage of the Marine Mammal Protection Act (MMPA) in 1972, the population has steadily increased at a rate of 5% per year (NMFS 1997). Harbor seal populations have also experienced significant increases since the passage of the MMPA (NMFS 1997). Within Washington State, the harbor seal population decreased during the 1940s and 1950s in part as a result of the state-financed bounty program[15] (Carretta et al. 2005). Overall, from 1983 to 1996 the Washington coastal harbor seal population increased annually at a rate of 4%, but it declined at a rate of 1.6% from 1991 to 1996, suggesting that the population exceeded equilibrium (Carretta et al. 2005). In contrast, Steller sea lion populations have declined significantly throughout most of their range during the last 40 years (NMFS 1997). Steller sea lion populations worldwide have declined by more than two-thirds since 1980 (Trites and Larkin 1996). The only region where Steller sea lion populations are thriving is from Oregon to Southeast Alaska.

Localized population trend data for pinnipeds near the mouth of the Ozette River are not available, but it is assumed that the current number of pinnipeds interacting with Lake Ozette sockeye in the estuary and nearshore environment has increased significantly in the last 50 years, in accord with the regional population trends for these animals. It is further assumed that the increased abundance of pinnipeds in coastal Washington waters has increased the number of Lake Ozette sockeye killed by pinnipeds. NMFS (1997) concluded that pinniped predation on salmon populations can act as an additional factor in salmonid population declines and can affect recovery of depressed salmonid populations in some situations. In Oregon State the Independent Multidisciplinary

[15] Over 17,000 harbor seals were killed by bounty hunters between 1943 and 1960 (Newby 1973 *in* Carretta et al. 2005).

Science Team ([IMST] 1998) concluded that a robust predator population could suppress recovery of depleted wild stocks of salmonids.

5.2.2.2.2 Abandonment of Ozette Village

Ozette Village was one of the five Makah villages. The pre-European-contact human population size of the village is unknown. The village was located near Cape Alava, about 2 miles southwest of the Ozette River, and much of the subsistence needs of the people living there were obtained from the ocean. Ozette villagers were avid sealers and the village provided an excellent location for fur seal hunting. Fur seals were hunted off of Umatilla Reef, where the seals were only 3 miles from shore. Female fur seals were the main pinniped harvested by Ozette villagers. In addition to the village, seasonal fishing stations were also located along the Ozette River near the mouth, Lake Ozette's outlet, and the south end of the lake near the spawning beaches. In early times a weir and trap were used to capture migrating sockeye in the lower river, while spears, dip-nets, and drift nets made of nettles were used to capture sockeye in the upper river and lake. It is assumed that during this period, competitors such as harbor seals and river otters were likely hunted in the lake and river by tribal fishermen and hunters.

In 1893, the Ozette Reservation was established by Congress to protect the rights of 64 villagers living there (Wray 1997). The population decreased in 1896 when natives were forced to move to Neah Bay so that their children could attend school. By 1914 there were only 17 natives remaining at Ozette and by 1932 there were only two (Wray 1997). The abandonment of the village and traditional fishing and hunting places and techniques was a slow process. By the late 1970s, all traditional hunting and sockeye fisheries in and along the lake and river ended. The end of traditional native fishing and hunting in the lake and river during the last 100 years has likely increased the number of sockeye predators.

5.2.2.2.3 Decreased Sockeye Abundance

As with other prey-predator interactions across global ecosystems, healthy populations of prey species (e.g., salmon) often overwhelm predators (e.g., pinnipeds) by migrating in mass past interaction points, reducing the total number and percentage of predator-prey interactions. Decreases in the number of adult sockeye returning and juveniles migrating from Lake Ozette in the past are thought to have increased the percentage of juveniles and adults preyed upon. In recent years the overall Lake Ozette sockeye population has increased, and it is likely that the predation rate has remained stable or decreased in the estuary and nearshore environment. However, there are no quantifiable data to calculate predation rates, let alone predation rates through time. There is at least one example from coastal Oregon where it was determined that larger proportions of the salmon run were preyed upon by harbor seals during years of lower salmon abundance than during years of higher salmon abundance (Brown and Mate 1983 *in* IMST 1998)

5.2.3 Directed Lake Ozette Sockeye Harvest

Currently no directed sockeye harvest occurs in the nearshore marine environment or the Ozette River estuary. Historically, the in-river sockeye fishery occurred near the mouth and at the lake's outlet; areas along the entire length of the river were also fished, but apparently not to the same degree as the two locations noted above. A trap was used to capture sockeye in the lower river, but it has not been used in the last 80 plus years. In interviews with Makah fishermen in 1941, Swindell (1941) asked about the use of this trap and none of the fishermen present could remember the last time it was fished. After trapping was abandoned, set nets were the primary fishing method used (Brennan 1941; WDF 1955).

Commercial tribal sockeye harvest was discontinued in 1977. A tribal ceremonial and subsistence fishery took place in the river from 1978 to 1982. No directed sockeye harvest has taken place since the cessation of the tribal ceremonial and subsistence fishery. Past sockeye over-exploitation in fisheries has been described as a factor for the decline of Ozette sockeye by several investigators (Dlugokenski et al. 1981; Jacobs et al. 1996; Gustafson et al. 1997; MFM 2000). The small size of the Ozette River during the sockeye run makes sockeye especially susceptible to net fisheries. Sockeye harvest data from 1948 through 1977 depict a decreasing trend in catch through time; note there are no harvest data prior to 1948 (Figure 5.2). For additional fisheries impacts see Sections 5.3.5, 5.6.1.1, 6.2.1.6, 6.2.2.2, 6.2.12.6, and 6.2.13.1.

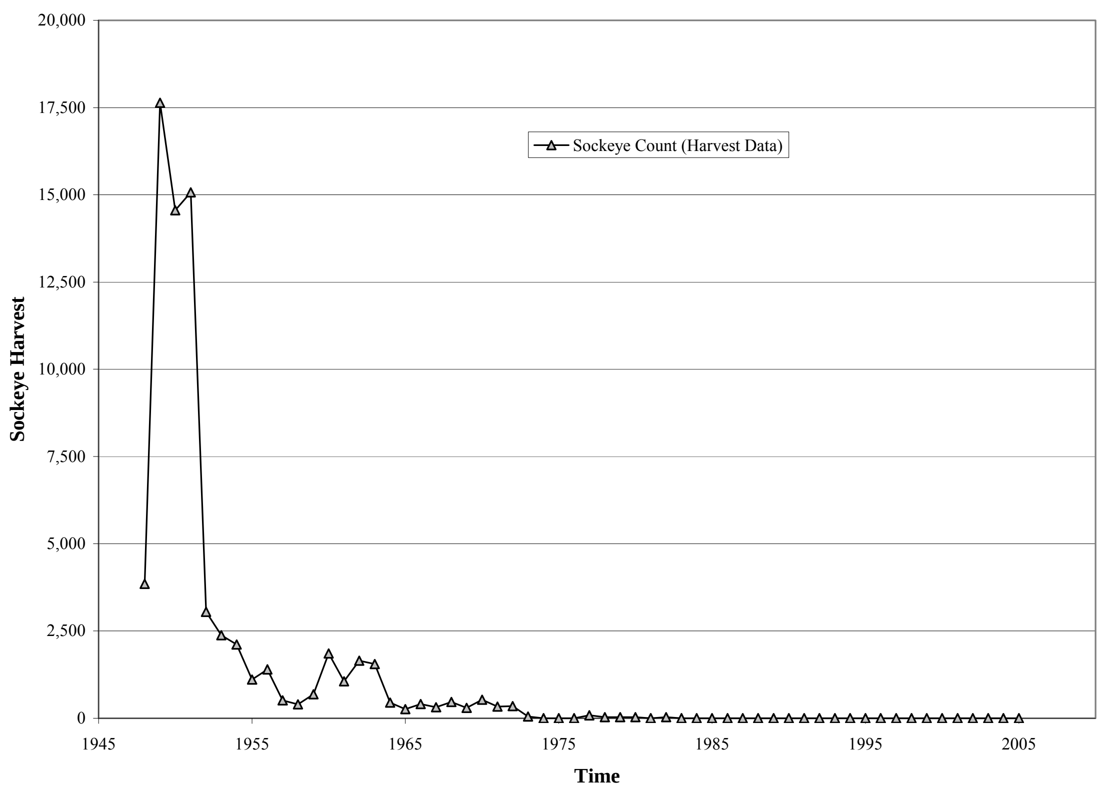

Figure 5.2. Makah tribal harvest of Lake Ozette sockeye (source: WDF 1955; Jacobs et al. 1996).

5.2.4 Nearshore Environment

The remote and relatively pristine nature of the shoreline in the vicinity of the Ozette River is reflected in the diversity and abundance of marine life in the area. Physical changes to the nearshore environment have not been documented, but changes in nearshore productivity are thought to vary significantly by season (see below). Changes in juvenile predator abundance and food availability are likely to affect early marine survival. Most marine mortality occurs shortly after marine entry (Peterman 1982).

The long freshwater lake holding behavior of Lake Ozette sockeye necessitates sufficient energy supplies for survival during the several months they spend without feeding. Food availability and growth are important factors in successful reproduction (Tyler et al. 2001), and maturing adult sockeye salmon during their last 5-6 months at sea will consume as much food as in all previous months at sea combined, doubling their body weight (Brett 1983 *In* Tyler et al. 2001). In the Strait of Juan de Fuca, Beacham (1986) found that the dominant prey (by volume) of sockeye >21.5 inches FL were euphausiids, amphipods, crab larvae, and mysids. The occurrence of empty stomach contents was 30%. The effect of changes in the early marine juvenile rearing conditions and late-stage marine life history of Ozette sockeye is unknown. Available marine survival estimates for Lake Ozette sockeye indicate relatively high marine survival.

Variability in the climatic and oceanic systems can alter the productivity of the nearshore ecosystem, and thus nutrients available to sockeye. For example in 2005, warm sea surface temperatures (SSTs) were observed by NOAA off the coast of central Oregon and extending to British Columbia. This phenomenon was reflected in satellite images, showing warm water off the mouth of the Columbia River extending up toward Vancouver Island, largely due to breakdown of the wind-driven currents that drive upwelling of cold, nutrient-rich water. During these warm SST's, observers did not find the typical dense aggregations of pelagic fishes that occupy the mid portions of the water column along the shelf break; rather, the fish were dispersed along the shelf break and upper slope areas. After mid July, 2005, observers documented a return of deeper waters upwelling to the surface as a result of strong winds from the north. Phytoplankton, which form the base of marine food webs, are dependent on these nutrient-laden waters for their growth and proliferation. Sockeye salmon growth in coastal waters can be expected to vary over years to decades as ocean productivity wanes and waxes.

5.3 OZETTE RIVER

Lake Ozette sockeye use the Ozette River as a migratory corridor during the smolt emigration and adult migration life history phases (see Sections 3.1.1 and 3.1.9). Sockeye spawning in the Ozette River has never been documented, but there remains the possibility that some sockeye spawning could occur in portions of the Ozette River. The smolt emigration and adult migration life history phases in the Ozette River are the focus of the limiting factors discussion presented in this section. Logjam and LWD removal (see Section 1.5.5 and 4.3.3), streamflow (see Section 4.3.6), water quality (see Section 4.3.5), predation (Sections 2.2.8), disease, and directed sockeye harvest are all factors that currently limit or in the past have limited sockeye salmon survival and productivity in the Ozette River.

5.3.1 Instream LWD Conditions

A full description of the LWD conditions in the Ozette River is provided in Section 4.3.3. In general, LWD size, frequency, and functionality are considered degraded from pre-disturbance levels. The majority of LWD reductions in the Ozette River are attributable to repeated LWD removal operations conducted over the last 100 years (e.g. Kramer 1953). Wood removal from the river appears to have been discontinued sometime in the mid-1980s, and LWD concentrations appear to be increasing. An intact riparian corridor along the Ozette River ensures a supply of future LWD.

5.3.1.1 Effects on In-River Habitat Conditions

The influence and importance of LWD on channel dynamics and stability, as well as fish habitat quality, is one of the most studied aspects of forest and stream interactions (Maser and Sedell 1994; Gregory et al. 2003; Montgomery and Piegay 2003). The ability of LWD to enhance fish habitat is well documented (Grette 1985; Bisson et al. 1987; Cederholm et al. 1997). Large woody debris has been shown to affect pool formation (Bilby and Ward 1989; Bilby and Ward 1991; Beechie and Sibley 1997), size, depth and quality (Haggerty and Ritchie 2004), and sediment accumulation and bar formation (Lisle 1986; Bilby and Ward 1989), as well as to sort and accumulate fine sediment and organic debris (Bilby and Ward 1989). All of these factors are thought to significantly influence the physical quality of fish habitat. Large woody debris can also act to provide cover and create channel complexity, which is critically important to some salmonid species such as coho (Nickelson et al. 1992).

Ozette River is a low gradient river with low and peak flows mediated by storage in the large lake it drains. Similar to other forested rivers in the world and the Pacific Northwest (see review above), wood plays an important part of the river's function, stability, and habitat complexity. At all Ozette River discharges of almost four orders of magnitude (4 cfs to 2200 cfs), wood interacts with the channel and flow. Due to the relatively large wood in and around Ozette River and its low gradient, wood plays an important role in roughening the channel and creating a backwater effect connecting the channel and its modest-sized floodplain. During high flows, large wood jams are responsible for maintaining most of the deep scour pools that exist along the river, except for several that are forced by rock-hardened river bends.

In addition, most suitable gravel spawning sites along the river have been created and maintained by the sediment trapping, scouring, and sorting mechanisms of large wood jams. While Ozette River is relatively starved of new, recent, coarse sediment, existing

LWD functions in trapping and sorting sediment that does enter the system (e.g., from Coal Creek) and aid in mobilizing fine sediment downstream or onto the floodplain.

The loss of large (>50 cm diameter) LWD in the Ozette River through removal has undoubtedly resulted in reduced habitat complexity throughout much if not all of the Ozette River (Section 4.3.3). Riparian forest removal adjacent to the upper 0.4 miles of the Ozette River has reduced LWD inputs, delaying the recovery and habitat potential of the upper river. Lake Ozette sockeye have not been observed spawning or rearing in the Ozette River, and therefore the direct effects on sockeye in the Ozette River are likely limited. As described earlier, the average duration of in-river adult migration is 65.2 hrs (Section 3.1.1). Smolt residence time in the river is thought to be similar to that of adults but no studies have been conducted to determine the quantity of time spent in the river by smolts.

Other species such as chum and Chinook salmon historically spawned in the Ozette River (Phinney and Bucknell 1975). The effects of wood removal on spawning habitat in the Ozette River are unknown, but chum and Chinook salmon populations experienced a precipitous decline in the years directly following the 1952 WDF wood removal project in the Ozette River. The decline in Chinook and chum salmon abundance likely can only be partially attributed to wood removal, and the effects of LWD removal on degradation of spawning conditions remains unclear. The decline also follows "high" sockeye, chum, and Chinook harvests in the previous 3 to 5 years. McHenry et al. (1996) describe the decline in local Chinook harvest during this period as interesting, and note that the decline coincides with the expansion of the British Columbia troll fishery.

5.3.1.2 Hydrologic and Hydraulic Effects

An initial investigation into the hydraulic influence of logjams on the water surface elevations of the Ozette River and Lake Ozette is summarized in PWA (2002). In 2004 and 2005, further model refinement and a detailed examination of the hydraulic and hydrologic effects of logjams in the upper Ozette River was conducted by Herrera Consulting (see Herrera 2005). Herrera (2005) developed a continuous hydraulic model of the Ozette River using an unsteady version of HEC-RAS. "Unsteady" refers to the model's acceptance of short time-step (one-hour) hydrograph input, to model differential flow conditions over time. The purpose of the model was to analyze the hydraulic effects of current, past, and variable wood loading scenarios on water surface profiles of the lake and river. Herrera (2005) modeled a reach extending 3,200 feet (975 m) downstream from the lake's outlet. This reach covered the upper portion of the river where wood was locally removed circa 1890 to 1950. The model reach covered only a portion of the Ozette River where WDF removed log jams in 1952. The upper 3000 feet of the river was presumably already free of large wood in 1952, because WDF did not remove any log jams there. Input parameters of the model included: channel geometry data (cross-sections and profile); floodplain conditions and constraints; continuous flow hydrographs; and channel and wood loading conditions. Channel and wood loading data were collected from the upper 1 mile of the Ozette River and are depicted in Figure 5.3.

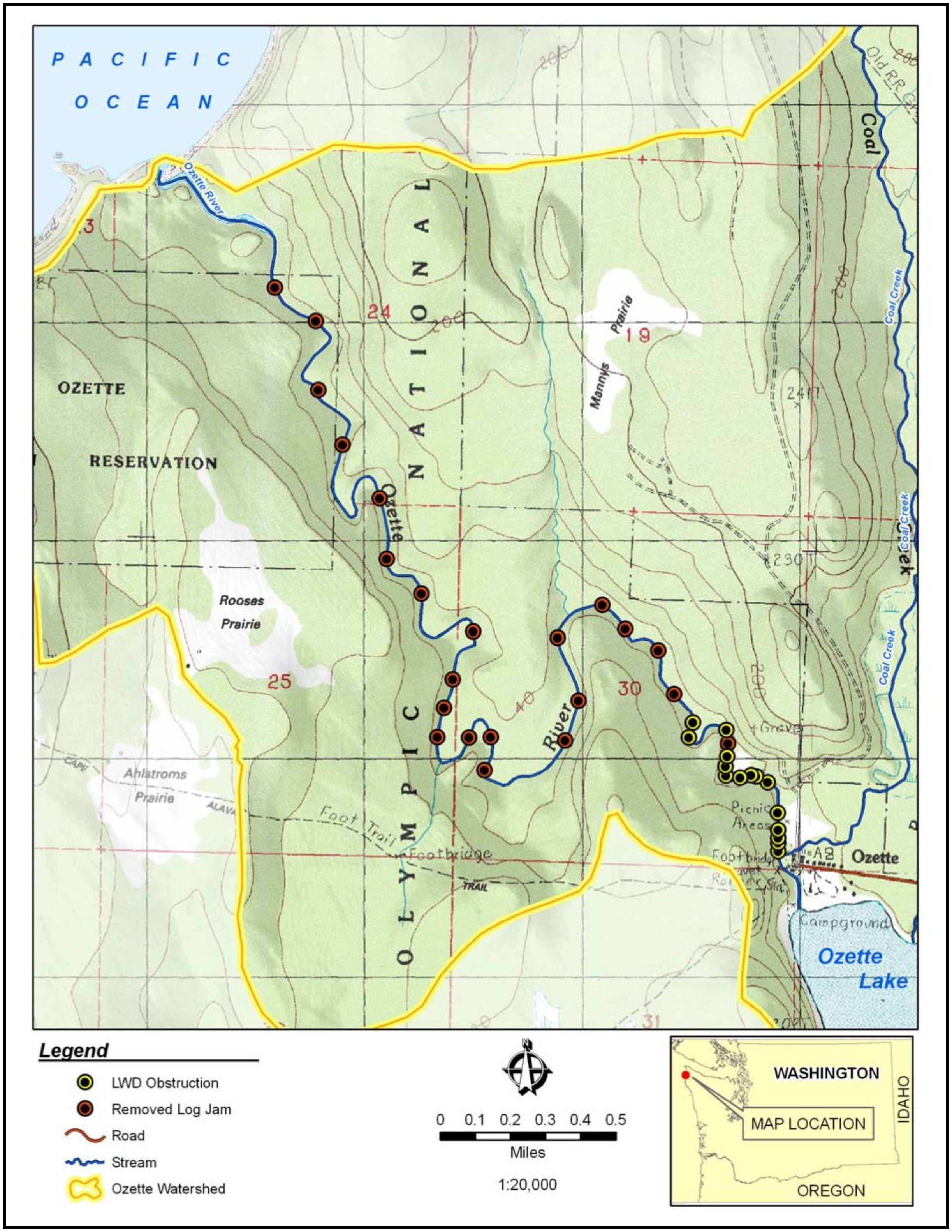

Figure 5.3. Location of large woody debris obstructions in July 2004 in the Ozette River and WDF logjam removal locations from summer 1952 (source: Kramer 1953; Herrera 2005).

Herrera (2005) modeled logjams using the obstruction feature of HEC-RAS to analyze hydraulic effects of logjams. The modeled period extended from December 1, 2003 through January 30, 2005. The model was calibrated using existing continuous discharge data from Ozette River and Coal Creek, wood loading conditions at existing log jams, and observed water surface elevations at surveyed cross-sections along the modeled reach. During the calibration, existing reach scale and local (LWD jam) channel roughness values were calculated from the HEC-RAS model. These roughness values were then used as a baseline for developing different wood loading scenarios (see below).

Upon model calibration to existing channel conditions and measured hydrographs from the Ozette River and Coal Creek stream gages, numerous wood loading scenarios were modeled. Jam spacing of 200, 500, and 1,000 feet and percent channel blockages of 0, 20, 40, 60, and 80 percent were used to represent a wide range of wood loading scenarios. One wood loading scenario included the current conditions of three "major jams" with a 20% increase in channel blockage. For each scenario, roughness values were altered locally along the study reach, as calculated from the continuum of various-sized jams in the initial calibration, supplemented by jam roughness and head loss values at other jams in western Washington.

Modeling results indicate that logjams in the upper 3,000 feet of the Ozette River exert a significant influence on both river and lake levels. The first three scenarios modeled by Herrera were (1) no logjams, (2) the current wood loading condition, and (3) the current wood loading condition but with increased jam size represented by an increase of 20% blockage at each jam (Figure 5.4). Results from wood loading scenarios of 200-foot jam spacing at 0, 20 40, 60 percent blockage are shown in Figure 5.5. Results from wood loading scenarios of 500-foot jam spacing at 0, 20 40, 60, 80 percent blockage are shown in Figure 5.6. Results from wood loading scenarios of 1,000-foot jam spacing at 0, 20 40, 60, 80 percent blockage are shown in Figure 5.7.

Note that for Figure 5.4 through Figure 5.7, the short-term (~one hour) discharge blips in the modeled hydrographs are a result of a model glitch that should be ignored. Future model runs will be able to correct these short-term errors, which are a result of poor floodplain definition in several upper cross-sections of the model (Herrera 2005). The short-term duration of these blips or spikes had a negligible effect on calculations of lake level elevation duration or averages.

While it is not possible to know exactly what the historical wood loading conditions were, especially in the upper 3000 ft of the river where wood was removed between circa 1890 to 1952, it is possible to estimate a range of likely wood loading scenarios. Kramer (1953) describes the removal of 26 large jams concentrated between RM 2 and RM 4 (mapped between RM 1 and 4.7 by Kramer [1953]), which, if evenly spaced, would result in a 400-foot to 750-foot average spacing. Undoubtedly, additional smaller jams (not channel spanning) existed that were not removed, pushing the spacing closer to ~500 feet. Herrera (2005) speculated that historical conditions were within the 200-foot spacing-60% blockage and the 500-foot-80% blockage range, based upon data, maps, and photos in Kramer (1953) and current wood conditions (Figure 5.5 and Figure 5.6). They assumed that wood load conditions in the upper Ozette River were similar to those documented by Kramer (1953) for the middle river because of similar historical riparian conditions, with additional wood in the upper river derived from floating wood from the lake blown into the head of the river by dominant winds from the south.

Herrera (2005) concluded from the modeling results that LWD jams have a significant influence on magnitude and duration of river and lake levels, but that timing appears to be essentially unaffected by variations in wood loading. Modeling results indicate that increases in lake level attributable to logjams are greatest during periods of high lake stage, moderate during median stages, and less during periods of low lake stage.

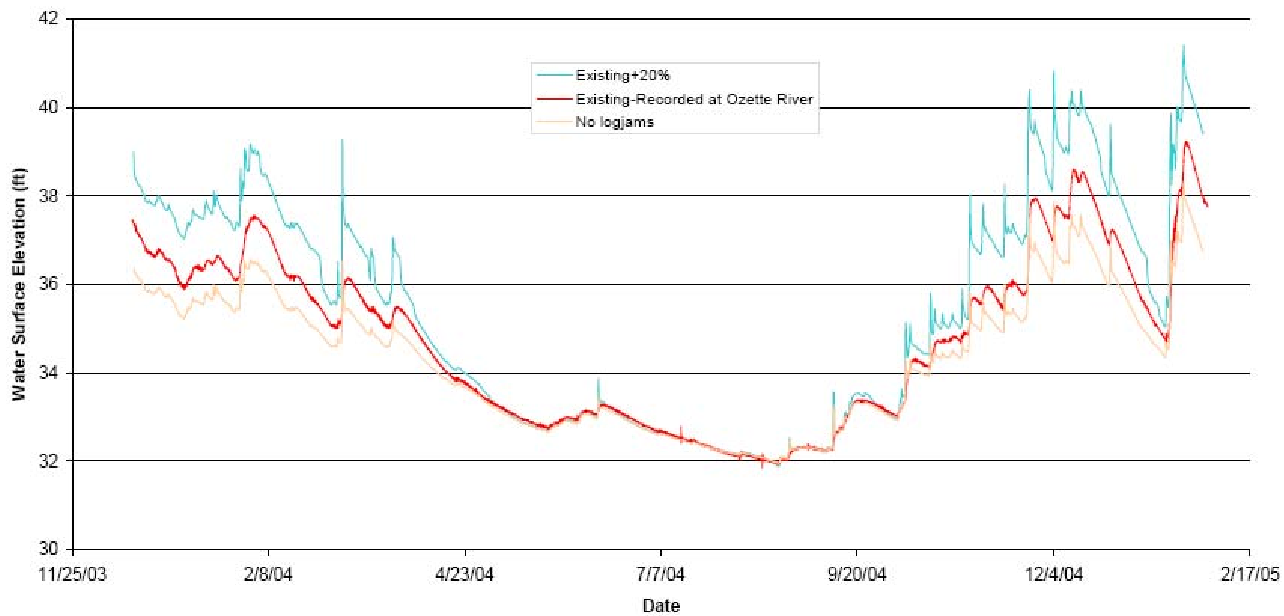

Figure 5.4. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, existing conditions plus 20% increase in jam blockage, and no logjams (source: Herrera 2005).

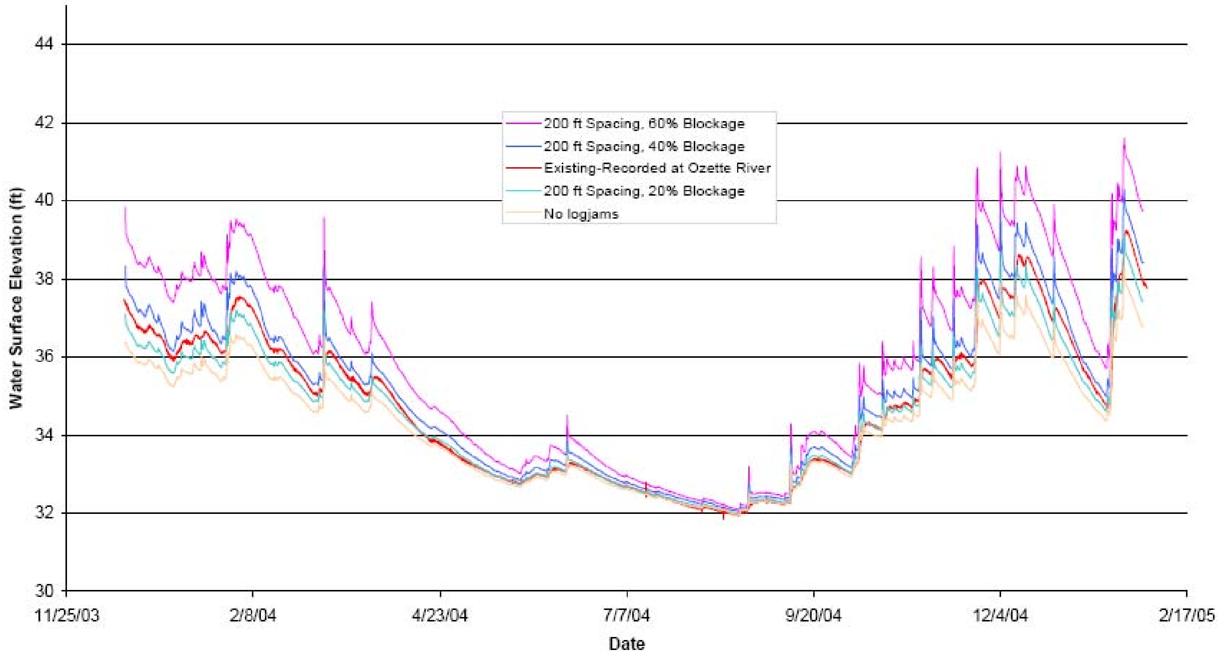

Figure 5.5. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, no jams, and 200-foot spacing at 20, 40, and 60 percent blockage (source: Herrera 2005).

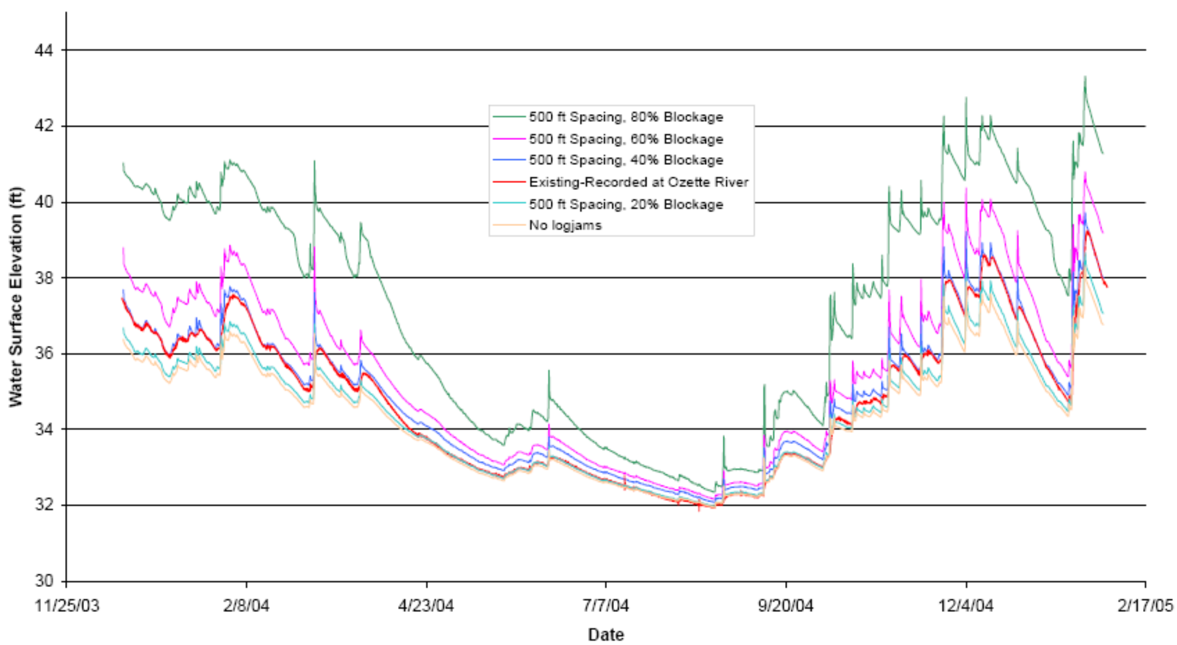

Figure 5.6. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, no jams, and 500-foot spacing at 20, 40, 60, and 80 percent blockage (source: Herrera 2005).

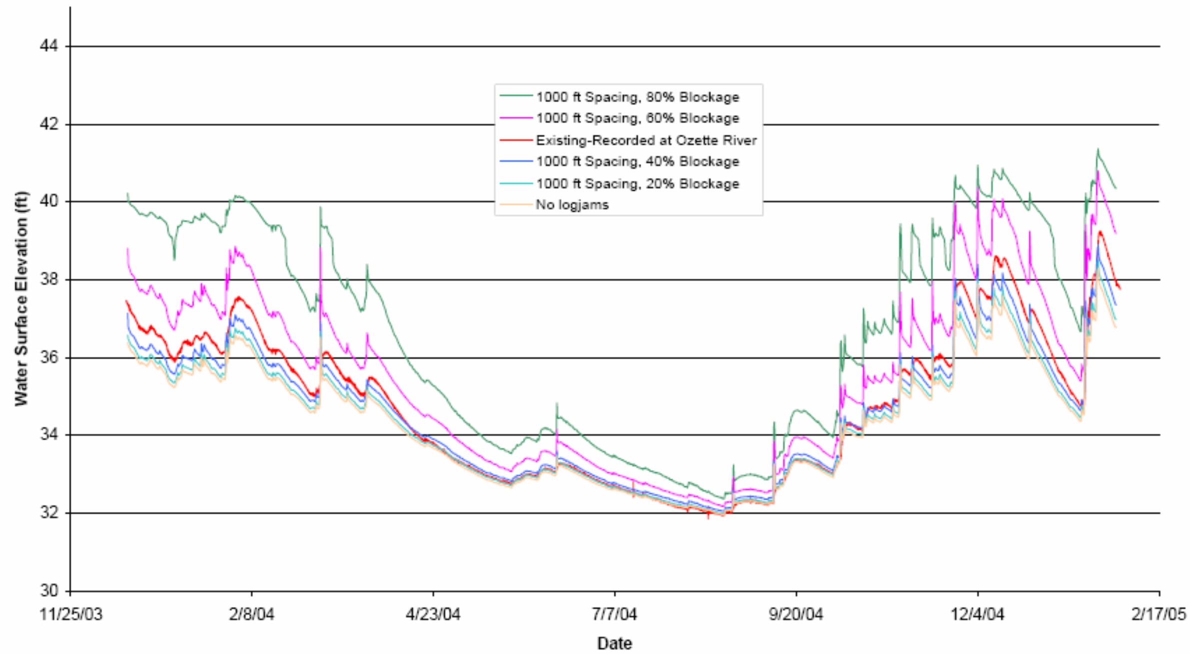

Figure 5.7. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, no jams, and 1,000-foot spacing at 20, 40, 60, and 80 percent blockage (source: Herrera 2005).

The percent blockage of jams was modeled after the existing shape and configurations of existing jams, with added number of jams and percent blockage, which tended to concentrate wood at the middle and high portions of the cross-section. Some large wood currently in or over the channel has been delivered by relatively recent windthrow or other disturbance (after the wood removal circa 1890 to 1980), resulting in wood that spans the channel instead of accumulating low in the channel. Historical photos in Kramer (1953) indicate that wood had accumulated low in the cross-section (potentially water saturated), rather than spanning from bank to bank. Historical, modeled, or real placement of LWD lower in the cross-section elevation would likely have larger influences on low and medium lake and river stages (Robin Kirschbaum, personal communication 2005; PWA 2002). Initial results from earlier studies that modeled wood lower in the cross-sections (PWA 2002) found that wood in the outlet had higher influences on medium lake and river stages, which would have a greater effect on summer lake levels, stream discharge, and vegetation colonization.

A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions. The unsteady HECRAS hydraulic model of the Ozette River would only need minor modifications for future use (Herrera 2005), but would need to be coupled with a distributed watershed model (e.g., DHSVM or similar) to simulate historical, current, and future lake inflow hydrology as a result of changes in land use, vegetation cover, drainage density, roads, and soil water storage.

Available modeled water surface elevation estimates indicate that jam removal has decreased spring and early summer lake levels and, as result, decreased streamflow during the spring and summer low flow period and decreased lake levels during lake beach spawning, incubation, and emergence periods. Furthermore, it appears that other factors such as the sediment accumulation at the mouth of Coal Creek have also decreased low flows at a given lake stage (see Sections 4.3.6.1 and 5.3.2.1; also see Figure 4.37, Figure 4.38, Figure 4.39, Figure 5.8, Figure 5.9, and Figure 5.10)

The direct effects on sockeye in the Ozette River from wood removal and its influence on lake and river stage are unclear. The effects of low flows on adult and juvenile sockeye salmon in the Ozette River are discussed in Section 5.3.2.2. NOTE: This particular limiting factor operates between geographical boundaries and is thought to primarily affect the conditions along the shoreline of Lake Ozette and therefore to affect sockeye salmon spawning and egg incubation at the spawning beaches (see Section 5.4.1 and 5.4.2 for further discussion).

5.3.2 Ozette River Hydrology

5.3.2.1 Peak Flows

The temporal spatial distribution of juvenile and adult sockeye in the Ozette River precludes them from exposure to peak flow events in the river. Any potential increases in peak flows in the Ozette River are thought to have a negligible effect on sockeye salmon.

5.3.2.2 Low Flows

Section 5.3.1.2 above discusses the potential effects of wood removal on both high and low lake levels and streamflows in Ozette River. Additional empirical data collected over the last 30 years suggest that additional factors have reduced Ozette River streamflow. As presented in Section 4.3.6, a significant change in the stage-discharge relationship occurred in the Ozette River between 1979 and 2002, indicating that discharges in Ozette River are lower for a given stage in 2002 than in 1979. For example, Ozette River stage (and lake level) was higher throughout the entire summer of 2002 than the summer of 1979, but discharge was generally only a fraction of that observed in 1979. Between June 1 and September 2, 2002, river stage ranged from 0.69 to 0.08 feet higher than during the same period in 1979, averaging 0.31 feet (Figure 5.8). However, streamflow during this period for 2002 ranged from 11% to 109% of that observed during the same period in 1979, averaging only 57% of 1979 streamflow. WY 2002 precipitation totals were higher than WY 1979 totals in every month from October to July (except February), as was stage (Figure 5.9). March through August precipitation totals were 32% higher in WY 2002 than WY 1979. Starting in early May 2002, in spite of higher rainfall and lake stage, Ozette River measured streamflows were less than flows in measured WY 1979 (Figure 5.10). Both measured rainfall and stage data indicate that streamflows would be significantly higher in 2002 than in 1979 in the absence of hydrologic changes.

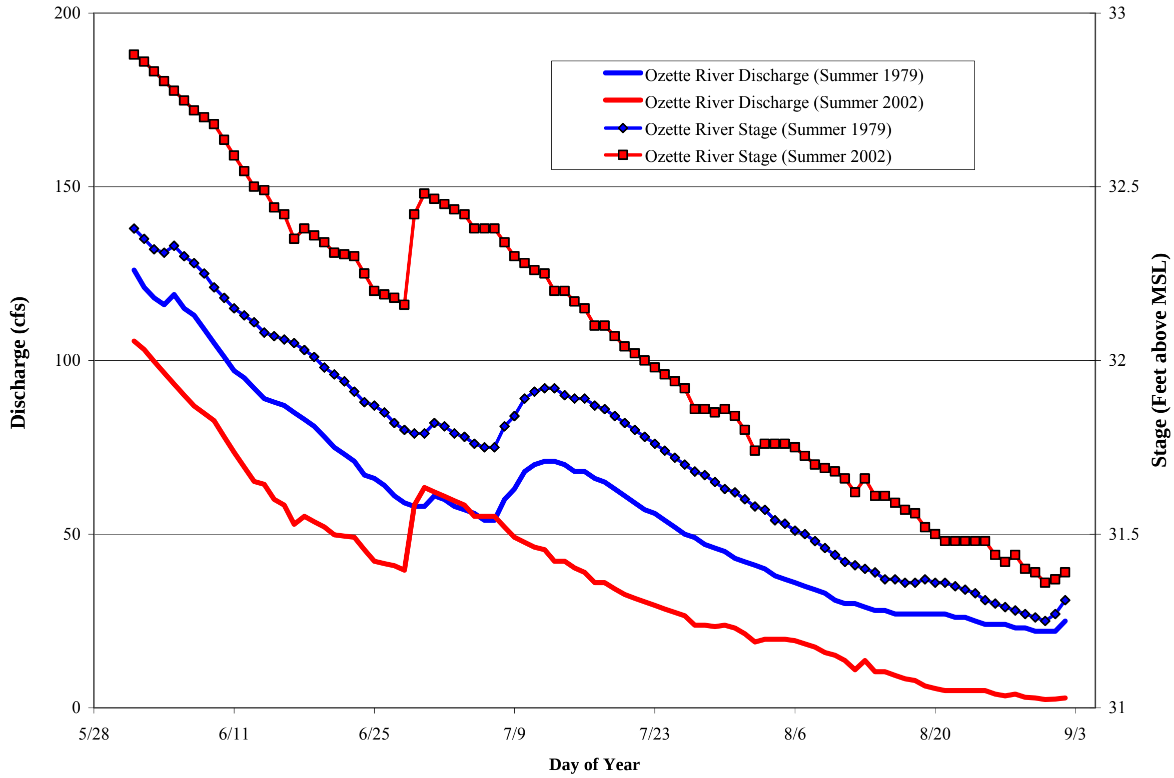

Figure 5.8. Comparison of Ozette River 1979 and 2002 summer low flow discharge estimates and stage data (source: USGS and MFM).

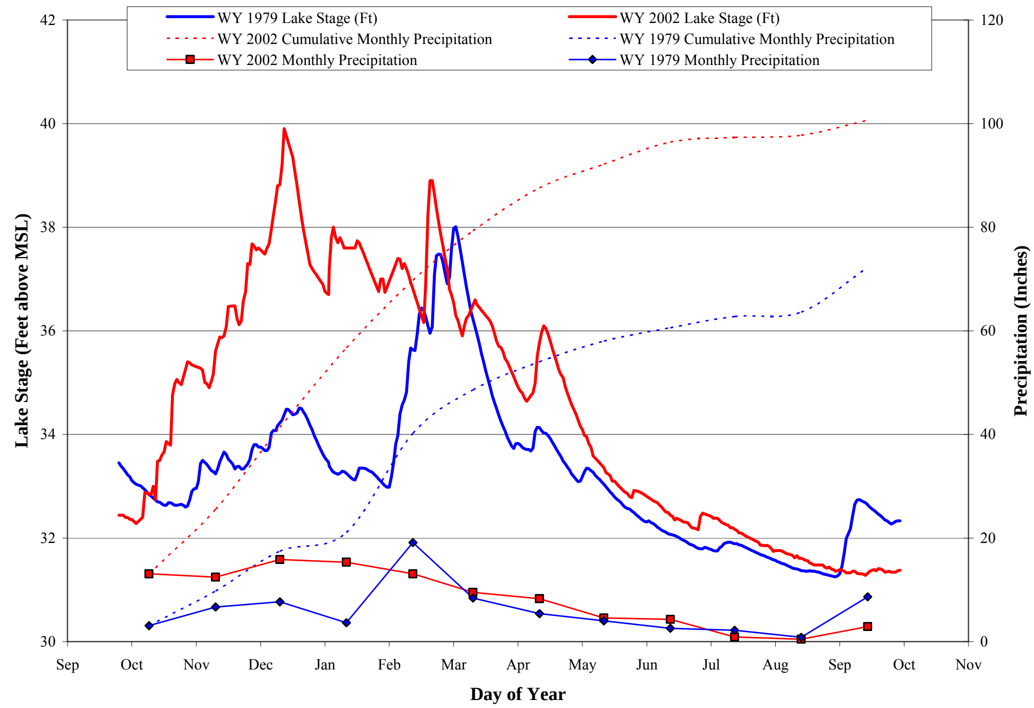

Figure 5.9. Comparison of Lake Ozette WY 1979 and WY 2002 lake stage and monthly and cumulative water year precipitation at Quillayute Airport (source: USGS and MFM, published and unpublished streamflow data; NOAA-NCDC 2005).

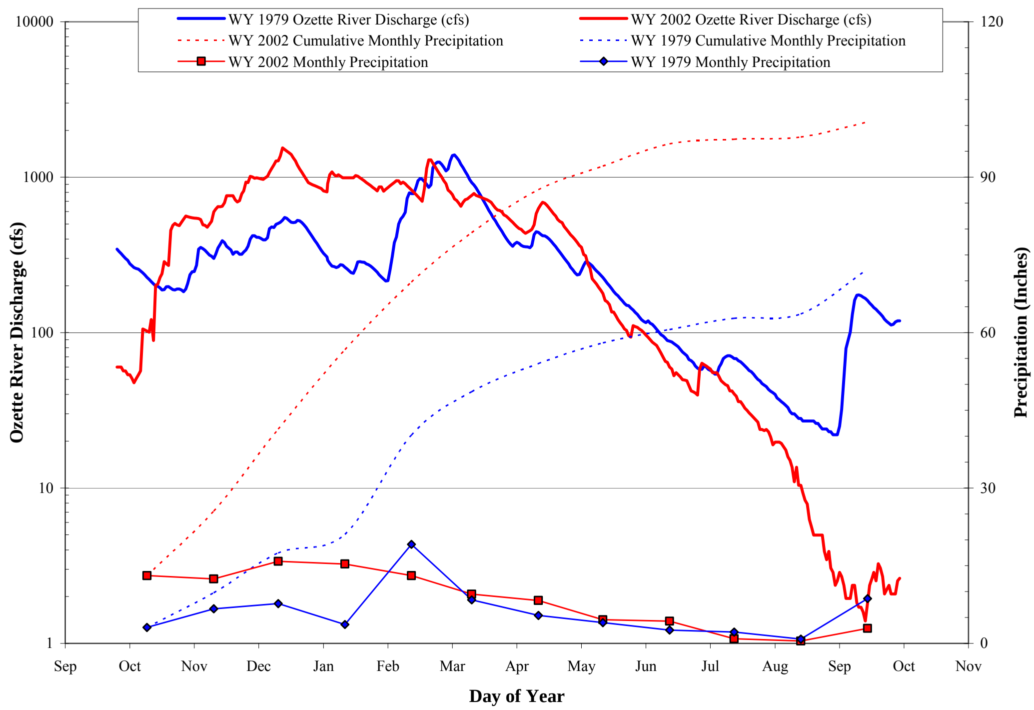

Figure 5.10. Comparison of Ozette River WY 1979 and WY 2002 streamflow discharge and monthly and cumulative water year precipitation at Quillayute Airport (source: USGS and MFM, published and unpublished streamflow data; NOAA-NCDC 2005).

5.3.2.2.1 Factors Affecting Low Flows

Available discharge data for the Ozette River at the lake outlet indicate a clear trend of decreasing baseflow (summer discharge) over time from the 1970s to 2000s (see Figure 4.44). The decrease is likely caused by multiple factors acting cumulatively over time. Identified factors include: climate, stage-discharge relationship, hyporheic flow, shoreline evapotranspiration, and tributary baseflow inputs. The following sections (Sections 5.3.2.2.1.1, 5.3.2.2.1.2, 5.3.2.2.1.3, 5.3.2.2.1.4, and 5.3.2.2.1.5) identify these factors and describe the mechanisms by which they may affect summer low flows in the Ozette River.

5.3.2.2.1.1 Climate

Available data do not indicate that climatic controls on precipitation or lake level have changed dramatically over time to influence Ozette River discharge. Rather, internal mechanisms are at play. The 2002 and 2003 dry-season summer rainfall and lake stage do not appear to be rare or uncommon events. Dry season summer rainfall and lake stage were also comparably low during the summers of 1967, 1982, 1985, 1992, 1996, and 1998 for rainfall (Figure 1.4) and lake stage 1985 and 1998 (Figure 4.13). As an example comparison, WY 2002 precipitation totals were higher than WY 1979 totals in every month from October to July (except February), as was lake stage (Figure 5.9). March through August precipitation totals were 32% higher in WY 2002 than WY 1979. Ozette River stage (and lake level) was higher throughout the entire summer of 2002 than 1979, but 2002 river discharge was generally only a fraction of that observed in 1979 (Figure 5.8).

5.3.2.2.1.2 Stage-Discharge Relationship

A significant change in the stage-discharge relationship occurred in the Ozette River between 1979 and 2002 (Section 4.3.6; Figure 4.37), indicating that discharges in Ozette River are lower for a given stage in 2002 compared to 1979. The shift in the rating curve has not been uniform and has been a result of different processes working at different stages or sections of the rating curve. The primary mechanism for changing the lower end of the stage-discharge relationship has been sediment deposition in the Ozette River from Coal Creek. Repeat channel cross-sections at the Ozette River Bridge from the 1970s and 2000s (Figure 4.38 and Figure 4.39) indicate that the channel thalweg has aggraded by 1 foot. This has affected the low-flow local-control on the release of water from the lake during summer months.

In addition, reach scale sedimentation from Coal Creek has aggraded the channel beyond the bridge cross-section to well downstream of Coal Creek, as indicated by field evidence of sand and fine gravel aggradation within the upper mile of Ozette River. This reach scale sedimentation, coupled with recent LWD recruitment has altered the medium and high rating curves during hydraulic conditions of reach scale channel control.

For reduced summer river discharges, it is hypothesized that reduced discharge at a given stage is primarily a function of reduced access to stored lake water below an elevation of 30 to 31 feet (NGVD 1929). As the lake draws down in the summer and baseflow inputs to the lake diminish in significance, Ozette River discharge becomes largely dependent on water stored in the lake from the previous rain events and the wet season.

5.3.2.2.1.3 Hyporheic Flow

As described above sedimentation at the mouth of Coal Creek has raised the hydraulic control of the lake outlet by 1-foot over the last twenty-five years. However due to the porosity of the sediment (silt, sand and fine gravel), hyporheic flow occurs through the sediment wedge. A fraction of the water that once flowed above the Ozette River bed may now flow within substrate interstices. Undoubtedly, hyporheic flow was always a component of discharge but the percentage of hyporheic flow to total flow may have changed due to sedimentation.

Extreme low discharge data presented in Section 4.3.6.2 indicate approximately a 30% increase in surface flow below the Coal Creek confluence. Recent discharge measurements both above and below Coal Creek indicate less contribution of hyporheic flow to surface flow (MFM 2007 unpublished data).

5.3.2.2.1.4 Shoreline Vegetation and Evapotranspiration

Between 1953 and 2003 there was a 56% reduction in unvegetated shoreline around Lake Ozette (Section 4.2.1). This reduction was due to shrub and herb vegetation colonizing unvegetated shoreline areas. This vegetation has increased summer evapotranspiration rates around the perimeter of Lake Ozette, potentially influencing lake levels and thus river discharge.

5.3.2.2.1.5 Tributary Baseflow Inputs

Few empirical discharge data exist for Ozette tributaries (Figure 4.33). However a detailed literature review of potential land-use impacts on stream discharge (Sections 5.5.1.2.1 and 5.5.1.2.2) indicate that the degree of forest plantation development and road network construction in the Ozette watershed could have altered the flow regimes of Ozette tributaries. More specifically, it is hypothesized that summer base flows to Lake Ozette have declined due to loss of fog drip, increased summer transpiration efficiency of water by young plantation trees, reduction in soil water retention due to road cuts and ditches, and less floodplain water storage (and release) due to channel simplification and incision. These hypothesized reductions in summer water inputs to Lake Ozette could translate to reduced Ozette River discharge.

5.3.2.2.2 Biological Effects

Reduced streamflow has the potential to affect water quality, predation rates and efficiency, and migration, reducing the fitness of migrating Ozette sockeye. The overall decrease in baseflow (summer discharge) during the sockeye migration periods remains unknown and the relative contribution of the factors identified in Section 5.3.2.2.1 is poorly understood, as are the biological effects. The most substantial reductions in streamflow occur from mid- to late-summer (when streamflows are naturally lower). Adult sockeye migrate through the Ozette River from early-spring through late-summer while most emigrating sockeye smolts transit the river during spring. The overall degree to which low flow changes affect emigrating sockeye smolts is unknown. Quantification of streamflow reduction during smolt emigration, and potential impacts remain a data gap. However, sufficient data exist to indicate that low summer flows likely impact adult sockeye migration.

Figure 5.11 depicts the 2003 adult sockeye return (plotted as daily percentage of the total return) contrasted with the observed 2003 Ozette River discharge and the theoretical historical discharge that would have existed prior to the shift in the stage-discharge relationship (i.e., 2003 stage data and the 1979 USGS rating curve). In RY 2003, approximately 8% of the sockeye entered the lake when streamflow exceeded 400 cfs and over 62% entered when streamflow was greater than 100 cfs. Approximately 10% of the RY 2003 sockeye entered the lake when flows were less than 35 cfs. The lowest flow in which sockeye were observed migrating was 11 cfs. A comparison of observed summer 2003 river stage and discharge data where streamflow was less than 100 cfs during the sockeye run, to the observed 2003 stage and discharge calculated using the old 1979 USGS rating curve and observed 2003 stage, indicates that streamflow averaged only 34% of what it would have been before the stage-discharge shift occurred.

Reduced streamflow at a given stage is thought to be primarily a function of reduced access to stored lake water below an elevation of 30 to 31 feet above MSL (Figure 4.38 and Figure 4.39). The overall degree to which baseflows have declined during the sockeye migration period remains somewhat unclear, because the complex interplay between the stage-discharge shift and other factors affecting Ozette River hydrology (see Section 5.3.2.2.1). The stage-discharge shift was not detected until 2002. However, available data indicate that the shift occurred slowly over time (Figure 4.37) with the most substantial changes occurring most recently. Reduced low flows during the sockeye migration period could affect water quality, predation rates and efficiency, and migration timing, reducing the fitness of migrating Ozette sockeye. However, the overall effect on Lake Ozette sockeye is unknown.

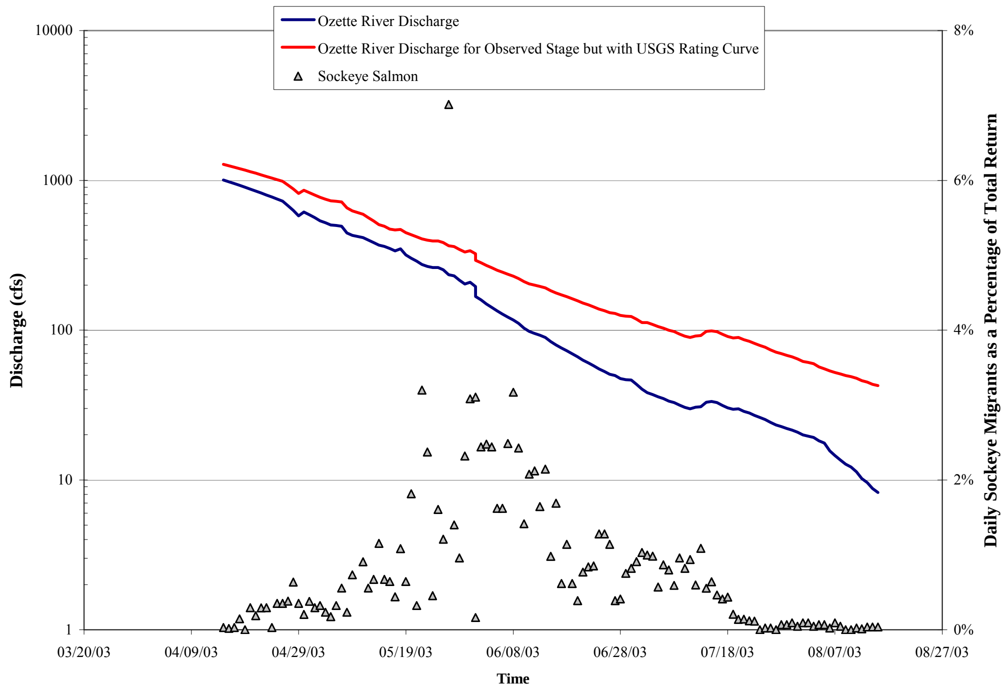

Figure 5.11. 2003 sockeye return (plotted as daily percentage of the total return) in relation to the observed 2003 Ozette River discharge vs. the theoretical historical discharge based on 1979 USGS rating curve (source: USGS and MFM, published and unpublished streamflow data; Haggerty 2005a).

5.3.3 Water Quality

Stream temperature and turbidity (suspended sediment) are the two primary water quality attributes identified that have the potential to limit sockeye salmon productivity and survival in the Ozette River. Water quality conditions in the Ozette River are described in detail in Section 4.3.5. The most significant potential effects of water quality on Lake Ozette sockeye salmon are mortality or decreased fitness resulting from temperature stress (e.g. increased susceptibility to disease or parasites), and mortality or decreased fitness from gill trauma caused by high concentrations of fine sediment during storm events. Fine sediment also affects pool characteristics in the Ozette River.

5.3.3.1 Stream Temperature

5.3.3.1.1 Effect of High Water Temperature on Sockeye Salmon

This subsection contains a brief review of the known lethal and sub-lethal effects of elevated stream temperature on southern North American sockeye stocks. Results from studies examining lethal effects of high water temperature vary by sockeye stock and life stage. Brett (1952) determined that 25.6°C was the upper lethal temperature threshold for juvenile sockeye salmon and that no sockeye salmon held at temperatures of 25°C for longer than one week could survive (method used: incipient lethal temperature). In thermal tests with adult Fraser River sockeye Servizi and Jensen (1977) concluded that thermal shock caused mortalities at temperature greater than 24°C, and a combination of thermal stress and *Flexibacter columnaris* (Chondrococcus columnaris) caused mortalities observed at 24°C, while mortalities observed at temperatures between 22 and 24°C were attributed to *F. columnaris*. Servizi and Jensen (1977) concluded that no mortality occurred after holding adult sockeye for 15 days at 21°C. Farrell and Hinch (2004) point out that the results of Servizi and Jensen (1977) may not be applicable to the "wild" situation because fish were pre-treated with oral antibiotics and dipped in fungicide.

Studies of Fraser River adult sockeye conducted in 2003 and 2004 found varying rates of mortality in holding experiments (Farrell and Hinch 2004). Adult late-run Fraser River sockeye held at 19.6°C experienced 50% mortality after 9 days, and sockeye held at 15.9°C experienced 50% mortality after 29 days. Adult Harrison River sockeye held at 18.0°C experienced 50% mortality after 16 days. DFO (2005) concluded that these results likely represent the worst-case scenario, because sockeye were handled several times and held in aquaria in order to conduct the studies. Kemmerich (1945) attempted to hold (in Umbrella Creek) adult Lake Ozette sockeye captured at the lake outlet. The water temperature in Umbrella Creek was 18°C, and these sockeye experienced a 72% mortality after 7 days. Other attempts to hold sockeye for prolonged periods in Lake Ozette and the Ozette River have resulted in fungal growth on sockeye, as well as high mortality rates (MFM unpublished data; Kemmerich 1945)).

Fraser River sockeye researchers have also found a correlation between accumulated temperature units (ATU) or degree-days and pre-spawning mortality. When sockeye are exposed to 450 to 500 ATUs, they are more likely to die prior to reaching the spawning grounds (DFO 2005). Since 1995, several stocks of Fraser River sockeye salmon have experienced extremely high rates (occasionally exceeding 90%) of in-river en route and pre-spawning mortality (Cooke et al. 2004). High in-river Fraser River sockeye mortality rates documented after 1995 prompted intensive monitoring of in-river environmental conditions, as well as sockeye run timing, migration rates, and physiological studies (DFO 2005). In 2004, nearly 72% of the in-river sockeye run (including early Stuart, early summer, summer, and late-run stocks) could not be accounted for on the spawning grounds (DFO 2005). Fraser River researchers used two simple models to estimate total mortality of all stock groups based on temperature alone and estimated mortality at 45% to 88% for the 2004 sockeye run (45% Late, 72% Early Stuart, 88% Early Summer and Summer; DFO 2005).

High water temperatures have been shown to result in delayed sockeye migration. In the Okanagan River, sockeye migrations cease when water temperatures exceed 21°C and resume when temperatures fall below 21°C (Hyatt et al. 2003). Fraser river sockeye researchers have found more general relationships between elevated water temperatures and sub-lethal effects to sockeye. DFO (2005) concluded that high water temperature in the Fraser River led to direct mortality, and sub-lethal effects included fungal and bacterial growth, delayed migration, increased physiological stress, decreased energy reserves to reach spawning grounds and spawn successfully, and increased mortality following non-lethal fisheries encounters. Specific data on water temperatures, sockeye exposure times, and resulting sub-lethal effects are generally lacking in the sockeye literature. In the Fraser River system, late-run sockeye entering the system earlier than normal are exposed to warmer than normal water temperatures. This has been found to result in a higher accumulation of temperature degree days, promoting a rapid proliferation of *Parvicapsula* and other infections (DFO 2005).

5.3.3.1.2 High Temperature Impacts on Lake Ozette Sockeye Salmon

The impact of high water temperatures in the Ozette River on Ozette sockeye is not fully understood. In order to evaluate temperature regimes experienced by migrating sockeye in the Ozette River, average daily mean and maximum stream temperature was examined relative to run timing. Composite average mean and maximum daily stream temperature were calculated from years where data existed (mean temp n=4; max temp n=6; analysis excluded data collected in 1999, when temperature data was collected only in the upper section of the estuary). Figure 5.12 depicts the composite average mean and maximum daily stream temperature in the Ozette River compared to a composite average of the daily cumulative proportion of adult and juvenile migrants entering and exiting lake Ozette (for adult sockeye this includes return years 1998 through 2003; data from 2002 and 2004 were used to generate the smolt cumulative run curve).

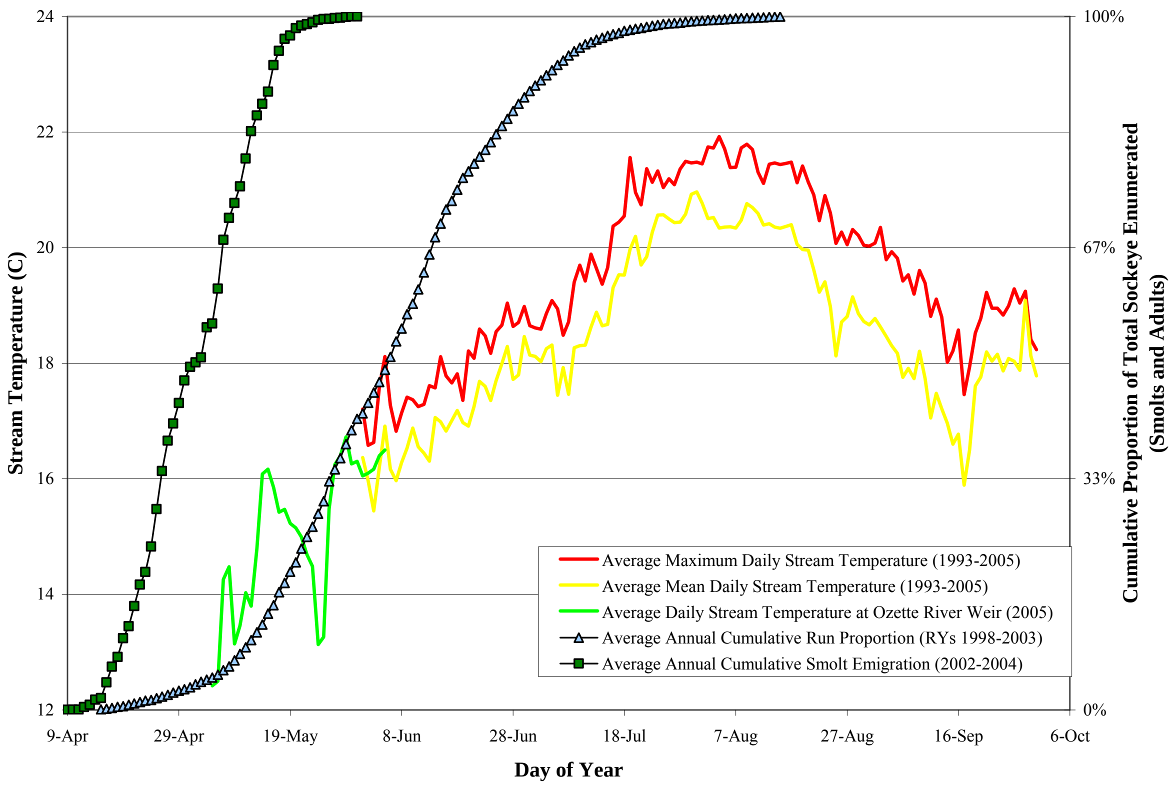

Figure 5.12. Comparison of Ozette River daily average mean and maximum stream temperature observed from 1993 through 2005, Ozette sockeye smolt emigration timing (2002-2004), and adult run timing (RY 1998-2003). Data sources: Peterschmidt and Hinton 2005 (smolt data); Haggerty 2004a, 2005a, 2005b, 2005c, and 2005d (adult data); Meyer and Brenkman 2001 and MFM, unpublished data (water temperature).

Temperature data during the peak smolt emigration period is generally lacking for the Ozette River. However, temperature data collected in May 2005 and data collected in June 1994 and 2002-2005 indicate that mean temperatures are likely less than 16 °C during most years. Based on smolt trapping data collected from 1979 through 2004, only a small fraction (<<5%) of the average annual smolt emigrants exit the lake after May. Maximum observed temperatures from June 1 to June 15 range from 16.6 to 20.0 °C. Brett (1952) determined that preferred temperature for juvenile sockeye was between 12 and 14°C; physiological optimum is 15°C (Brett 1971 *in* Pauley et al. 1989). Currently stream temperatures during the smolt emigration do not appear to pose any risk to the survival of the vast majority of emigrating smolt. However, future temperature sampling in the Ozette River should begin in April so that long-term trends in timing and temperature can be evaluated in the future.

Maximum stream temperatures approaching 24°C have been recorded during the adult sockeye migration period (MFM unpublished stream temperature data). Data included in Figure 5.12 indicate that 52.3%, 10.8%, 1.5% and 0.0% of the average annual run enter the lake when average mean daily stream temperature in the Ozette River exceeds 16°C, 18°C, 20°C, and 22°C respectively. These data also indicate that 57.2%, 26.2%, 2.5%, and 0.0% of the average annual run enter the lake when average maximum daily stream temperature exceeds 16°C, 18°C, 20°C, and 22°C.

However, the relationship between average daily mean and maximum temperatures and average run timing does not represent the temperatures experienced by individual returns. Therefore, all paired temperature and run timing data were compared by run year. These data were only available for RYs 2002-2004. Figure 5.13, Figure 5.14, and Figure 5.15 depict Ozette River stream temperature and sockeye run timing for return years 2002, 2003, and 2004. Interestingly, the percent of sockeye migrating up the Ozette River when daily mean stream temperature exceeded 18 °C ranged from 16.3% (RY 2003) to 55.9% (RY 2004), averaging 31.2% (~3 times greater than the values predicted from Figure 5.12). The percent of sockeye migration that occurred when daily maximum stream temperature exceeded 20 °C ranged from 5.6% (RY 2003) to 28.2% (RY 2004), averaging 14.1% (~6 times greater than the values predicted from Figure 5.12).

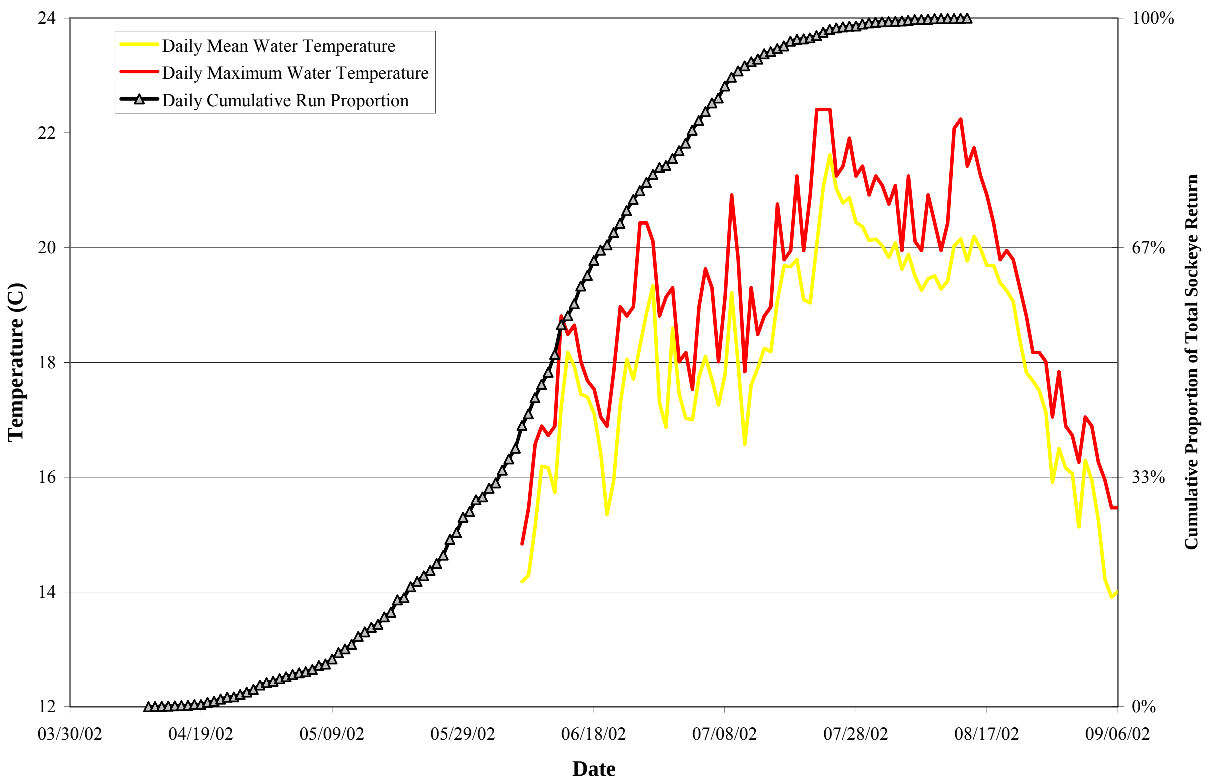

Figure 5.13. Ozette River maximum and average daily stream temperature in 2002 contrasted with RY 2002 cumulative sockeye run-timing curve (source: Haggerty 2004a [adult data]; MFM, unpublished data [water temperature]).

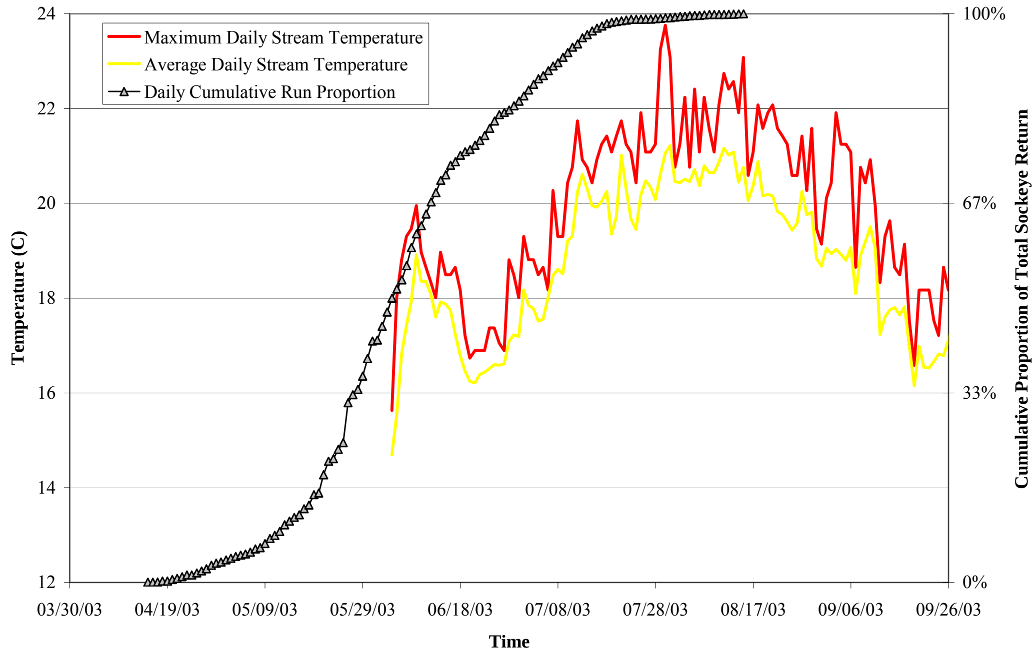

Figure 5.14. Ozette River maximum and average daily stream temperature in 2003 contrasted with RY 2003 cumulative sockeye run-timing curve (source: Haggerty 2004a [adult data]; MFM, unpublished data [water temperature]).

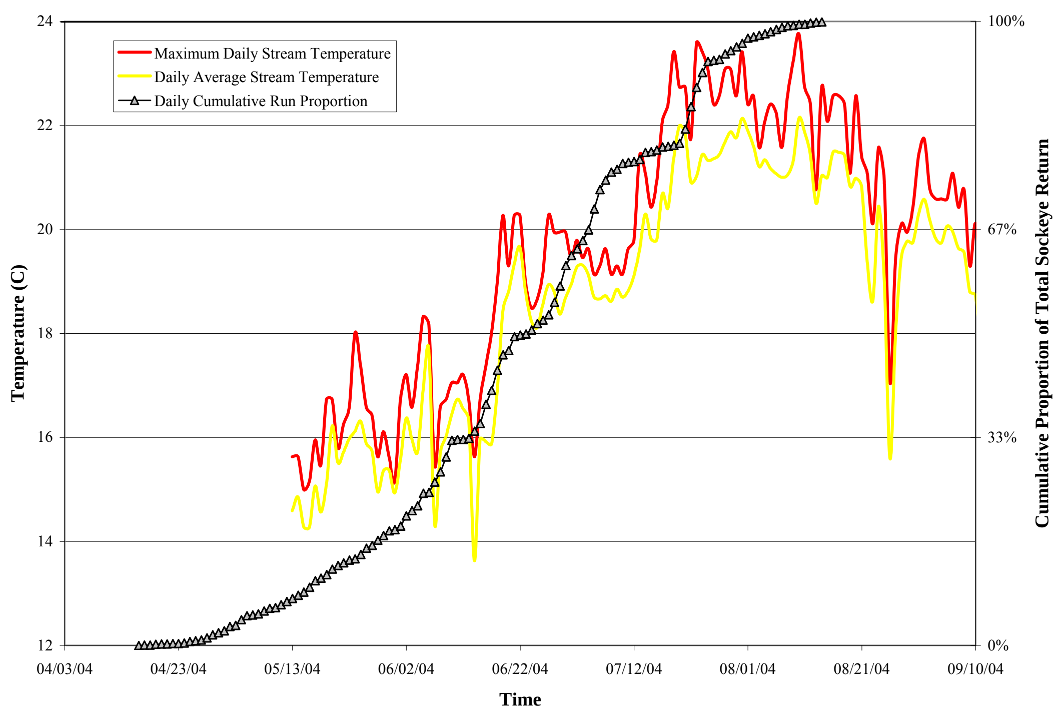

Figure 5.15. Ozette River maximum and average daily stream temperature in 2004 contrasted with the preliminary RY 2004 cumulative sockeye run-timing curve (source: Haggerty 2004a [adult data]; MFM, unpublished data [water temperature]).

The effects of high (>18°C) stream temperatures on sockeye salmon depend upon several factors, including temperature, exposure time, specific stock temperature tolerances, and more. Ozette River water temperatures are primarily a result of Lake Ozette surface temperatures, which are controlled by spring and summer air temperatures and heating days. Therefore, river (lake) temperature varies by annual climatic conditions (see Section 1.3.2). Stream temperature data collected during summer 2005 showed little temperature moderation in the first two miles downstream from the lake (Figure 4.32), suggesting that temperatures observed near the lake's outlet are an excellent indicator of downstream temperatures and overall temperatures experienced by migrating sockeye salmon. Late summer low flow temperatures may follow a different downstream pattern. In order to determine the proportion of the annual run exposed to different temperature ranges, the number of sockeye observed transiting the weir were categorized as being exposed throughout the river to temperatures recorded just downstream from the confluence with Coal Creek. Figure 5.16 depicts the proportion of adult Lake Ozette sockeye exposed to different temperature ranges in the Ozette River.

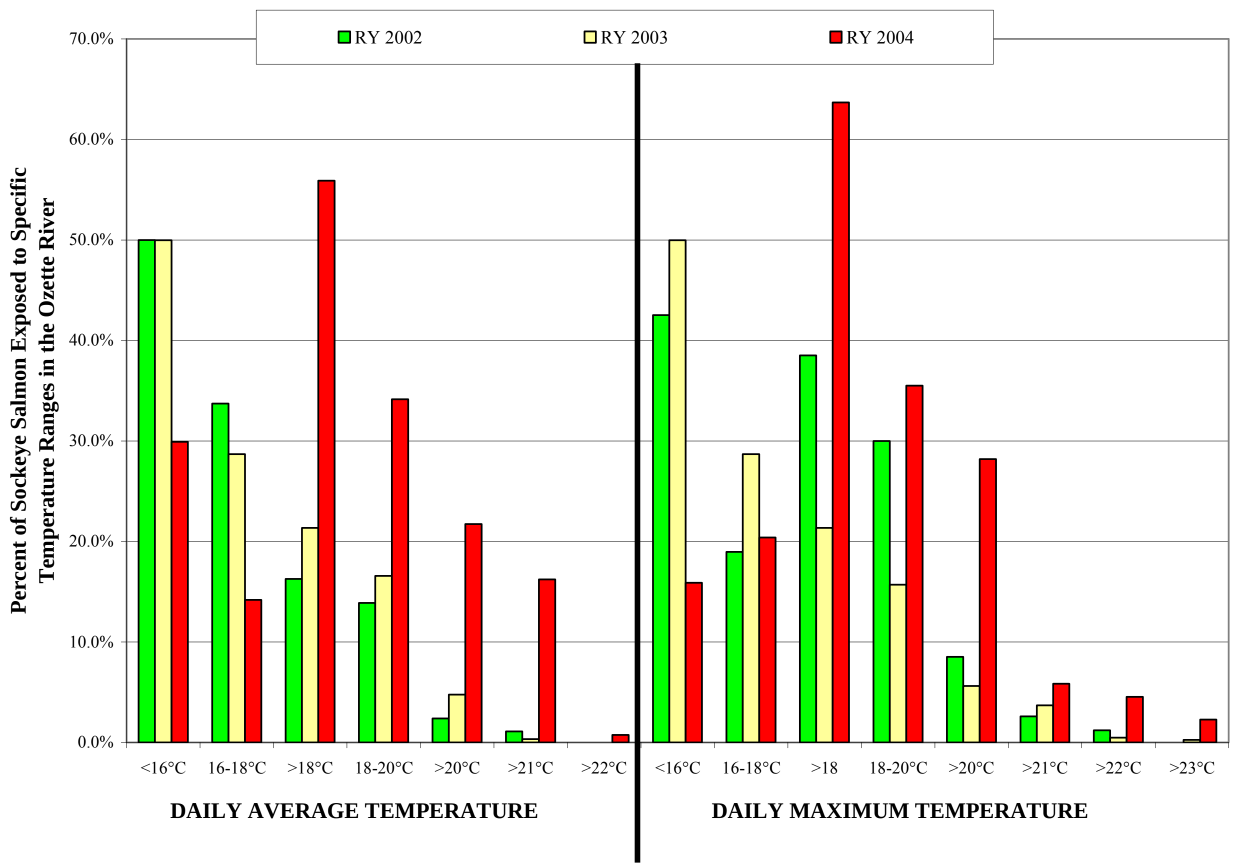

Figure 5.16. Estimated percentage of annual sockeye returns (RY 2002-2004) to Lake Ozette exposed to various temperature range categories (source: Haggerty 2004a, 2005a, and MFM unpublished data).

Gearin et al. (2002) reported that the mean transit time for adult sockeye from the estuary to lake entry in RY 2000 was 65.2 hours (Figure 3.4; range=17-154hrs). Sockeye may encounter excessive temperatures in the Ozette River, but their exposure time appears to be short. The effects of 2- to 4-day exposure to temperatures between 18-24 °C is not well documented in the scientific literature. However, it is important to note that some individuals linger in the river longer; approximately 8% of sockeye reported by Gearin et al. (2002) spent 6 to 7 days between the estuary and the lake. However, no studies specifically designed to evaluate Lake Ozette sockeye temperature tolerances have been completed. Therefore, we suggest a range of different impacts that could occur based on studies conducted with Fraser River sockeye (summarized in DFO 2005). Table 5.1 depicts the estimated proportion of Lake Ozette sockeye exposed to different temperature ranges during upstream migration and the potential biological effects for RYs 2002, 2003, and 2004.

Table 5.1. Proportion of Lake Ozette sockeye runs exposed to different temperature ranges during upstream migration and the potential biological effects (source: Haggerty 2004a, 2005a, and MFM unpublished data).

Average Daily Temperature Exposure	Percent of Sockeye Run Exposed to Specified Temperature Range			Potential Effects
	RY 2002	RY 2003	RY 2004	
<18°C	83.7%	78.7%	44.1%	No Direct Effect
18-19°C	6.6%	8.0%	5.0%	Decreased swimming performance, increased energy use
19-20°C	7.3%	8.6%	29.2%	Increased physiological stress, slow or delayed migration
20-21°C	1.3%	4.4%	4.8%	Increased risk of pre-spawning mortality and disease
>21°C	1.1%	0.3%	16.2%	Chronic exposure can lead to severe stress, direct en-route mortality, and delayed pre-spawning mortality

Jacobs et al. (1996) speculated that adult sockeye returning to Lake Ozette during periods when maximum daily stream temperatures exceed 18°C may be delayed because of high water temperatures. Some sockeye may be delayed in their return to the lake, but sockeye weir data indicate that Ozette sockeye migration continues even as water temperatures approach 24°C. In the Okanagan River, sockeye migrations generally cease when water temperatures exceed 21°C and resume when temperatures fall below 21°C (Hyatt et al. 2003). However, the Okanagan-Columbia river system is complex and provides more thermal refugia for sockeye.

In the case of Ozette River, once sockeye have begun their journey upstream, a behavioral response to high temperatures that delays migration will result in increased exposure to elevated temperatures. Sockeye that haven't entered the river could hold in the ocean or estuary until more favorable river conditions occur, but there is no evidence that migration ceases during high temperatures. The counting weir may delay migrants from entering the lake and increase their exposure time to elevated stream temperatures. Weir operations since 1998 have been conducted with the weir left open 24-hrs/day for free passage into the lake in order to minimize impacts of high water temperatures and predation caused by the weir.

High water temperatures in the Ozette River during adult migration are not known to result in significant direct en-route mortality. However, high temperatures probably make sockeye more susceptible to disease and infection. Elevated temperatures can promote fungal and bacterial infections, as well as secondary wound infection, making sockeye more susceptible to pre-spawning mortality. Monitoring of run timing and Ozette River stream temperature should continue in the future. An investigation of thermal refugia habitat in the Ozette River should be conducted to determine whether deep pools or springs exist that could provide holding habitat for migrants to reduce thermal stress.

5.3.3.2 Suspended Sediment and Turbidity

Elevated turbidity and suspended sediment concentration (SSC) have numerous negative impacts on fish and other stream biota, including behavioral effects, physiological effects, and habitat effects. Behavioral effects of turbidity and SSC on fish include changes in foraging, predation, avoidance, territoriality, homing, and migration (Waters 1995; Bash et al. 2001). Physiological effects include gill trauma and damage, reduced respiration, changes in blood physiology due to stress, disruption of osmoregulation during salmonid smolt migration, and reduced oxygen transfer to incubating eggs in gravel affected by sedimentation (Waters 1995; Bash et al. 2001). Habitat impacts include: changes in the abundance and diversity of prey (e.g., invertebrates and mircofauna); altered primary production (i.e., photosynthesis) (Waters 1995; Bash et al. 2001; Suttle et al. 2004); changes in temperature regimes (Waters 1995); increased channel sedimentation (Everest et al. 1987); increased gravel and cobble embeddedness (Bash et al. 2001); reduced gravel permeability, intergravel water flow and oxygen transfer (i.e., hyporheic flow); reduced gravel porosity and emergence success (McNeil and Ahnell 1964; Everest et al. 1987; McHenry et al. 1994; Reiser 1998); reduced pool habitat volume and habitat complexity (Lisle and Hilton 1999); and increased bedload mobility and scour depths (Lisle et al. 2000).

Sources of turbidity and SSC in the Ozette River are limited to inputs from Coal Creek and a few small tributaries that enter downstream of Coal Creek. Long-term turbidity and SSC data are not available for the Ozette River (see Section 4.3.5). For Coal Creek near the confluence with Ozette River, continuous turbidity and SSC data are available only for October 2005 to January 2006 (see Section 4.4.4.5).

The potential effects of elevated suspended sediment and turbidity levels on sockeye salmon in Ozette River were evaluated based on the estimated frequency of storm events during time periods when sockeye salmon are known to inhabit the river. Sockeye salmon use the Ozette River seasonally. Smolt emigration occurs primarily in April and May, with some limited emigration during March and June. Adult sockeye migration occurs from April through August, with very limited entry in September (MFM 1999 unpublished weir data; Kemmerich 1945). High suspended sediment loads entering the Ozette River during the adult sockeye migration are not extremely frequent, since precipitation levels decrease leading into early summer. However, during high intensity rainfall events in spring and summer, and when antecedent streamflow conditions and lake levels are low, high levels of suspended sediment do enter the Ozette River from Coal Creek during the sockeye migration period. Time lapse underwater video data and trap data collected 1999-2003 were used to determine the number of days when poor visibility or no visibility occurred. Note that these visibility events only include periods when streamflow direction of the Ozette River is reversed (see Figure 4.41) into Lake Ozette (the weir, trap, and video camera are positioned upstream of Coal Creek). Six such events occurred from 1999 to 2003, resulting in video image visibility classified as "non-viewable" (see Haggerty 2004a; 2005b; 2005c; 2005d) and approximately 12 events occurred when visibility was classified as "very poor." All events classified as non-viewable conditions (6) occurred either when daily precipitation was greater than 1 inch (25 mm) or when two-day precipitation was greater than 2 inches (50 mm). The frequency of such events at Ozette River near the confluence of Coal Creek (i.e., at the counting weir) during sockeye migration is shown in Figure 5.17 below.

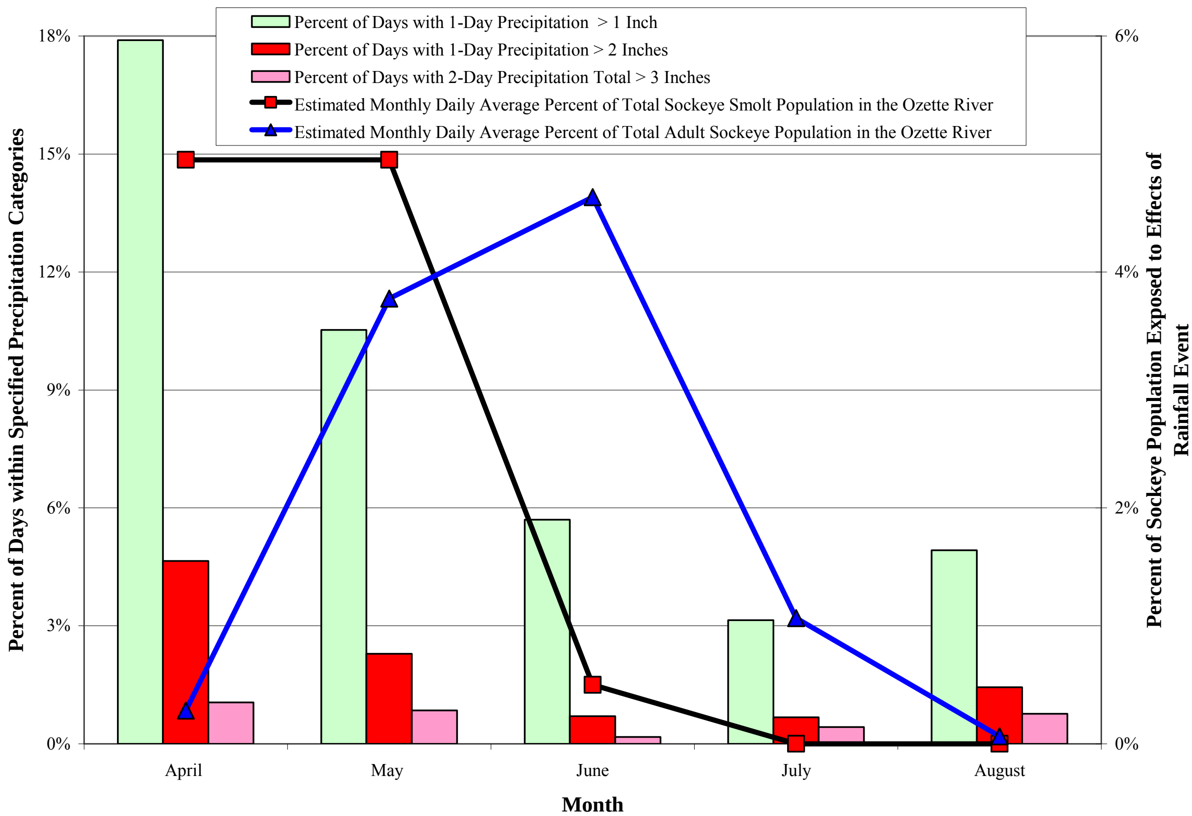

Figure 5.17. Spring and summer monthly summary of the percentage of days when 2-day and daily precipitation totals exceed specified ranges (Quillayute Airport Data 1967-2004) and the estimated monthly daily average percent of total adult and smolt sockeye population contained in the Ozette River (adult sockeye percent based on monthly daily mean proportion of sockeye run transiting the counting weir in RYs 1998-2003 [from Haggerty 2005d] and a mean 3-day residence time in the Ozette River; sockeye smolt percentage based on 2002-2004 smolt emigration data and a 3-day residence time in the Ozette River).

Preliminary sediment data collected in Coal Creek (Section 4.4.4.5.1) indicate that turbidity and SSC are correlated to both stream discharge and precipitation (rainfall). Using the available continuous sediment data from Coal Creek, relationships were developed between peak SSC and peak discharge for 19 different storm events (Figure 5.18). In addition, for these same 19 storm events, peak SSC was compared to the total 24-hour rainfall preceding the storm event (Figure 5.19). To determine average sediment concentrations for each of these 19 storm events, the average SSC was calculated from continuous data (See Section 4.4.4.5.1) from the initial rise in SSC during an event to the point that SSC values returned to base levels (i.e., the average SSC value from trough to trough of the sediment hydrograph). These average storm event SSC values were then compared to the total 24-hour rainfall preceding the storm event (Figure 5.20).

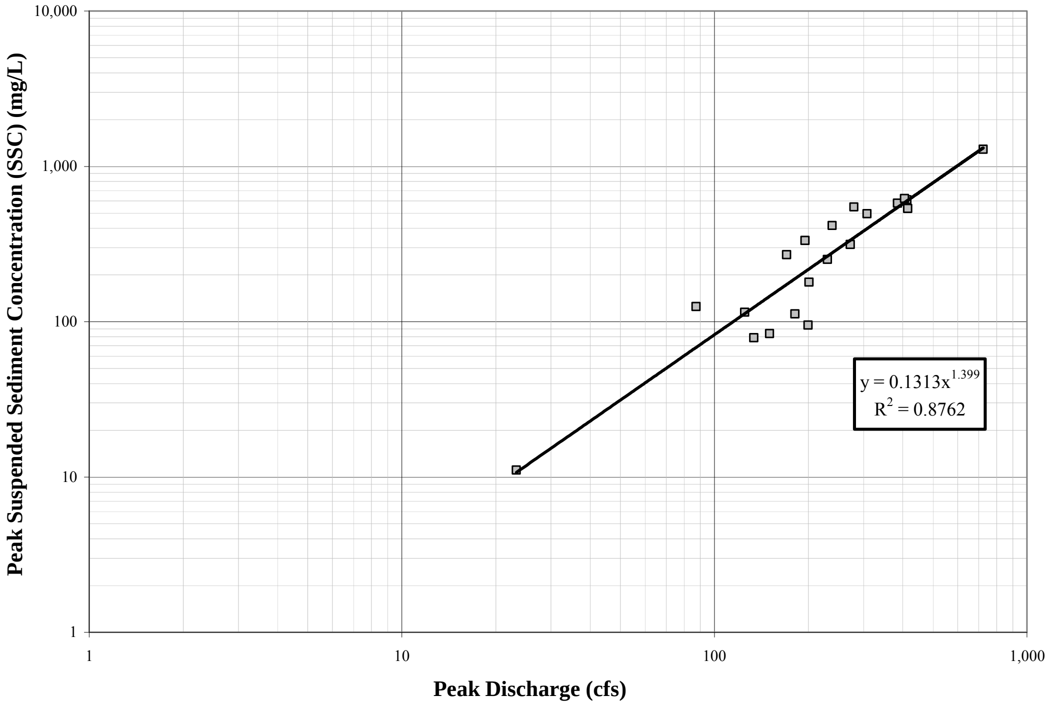

Figure 5.18. Correlation between peak discharge and peak SSC in Coal Creek near Ozette River (source: MFM, unpublished data).

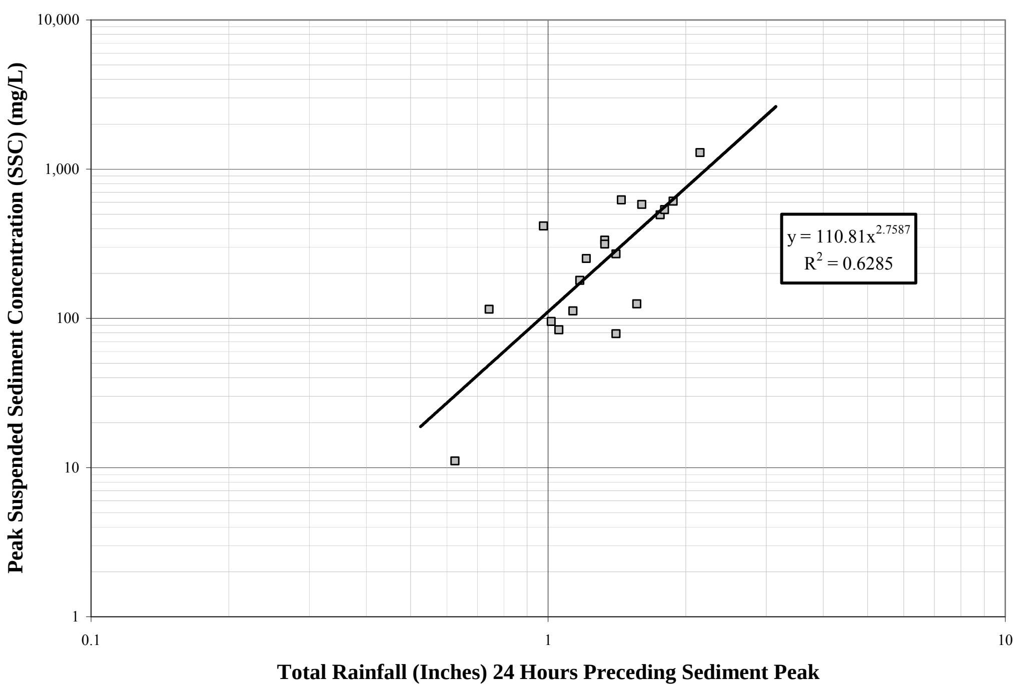

Figure 5.19. Relationship between total 24-hour rainfall and peak SSC in Coal Creek (source: MFM, unpublished data).

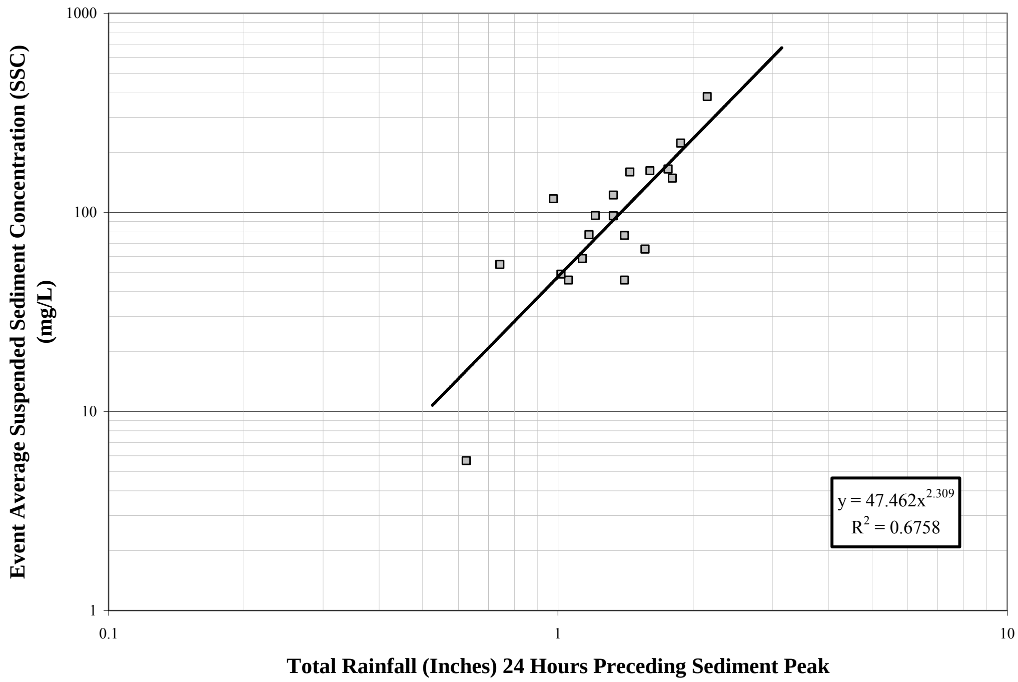

Figure 5.20. Relationship between total 24-hour rainfall and the event average SSC in Coal Creek (source: MFM, unpublished data).

These observational data indicate that for Coal Creek near the confluence of Ozette River, suspended sediment concentrations reach moderate peak values (100 mg/L) and average values (50 mg/L) after the 24-hour rainfall exceeds one inch. For rainfall events greater than 2 inches in 24 hours, peak SSC values exceed 600 mg/L, while average values exceed 200 mg/L. For the short period of sediment record at Coal Creek, major rainfall events have not exceeded 3 inches in 24 hours. However, available data (Figure 5.19 and Figure 5.20) predict that a 3-inch, 24-hour storm would produce peak SSC values exceeding 2000 mg/L, with average values around 500 mg/L. This is consistent with the projected trend of the turbidity-SSC rating curve for Coal Creek (See Section 4.4.4.5.1; Figure 4.82). From the 19 different sampled storm events, the average duration of the event was 14.3 hours, with peak concentrations lasting for 1 to 2 hours.

The data above can be used in conjunction with available empirical models of the physiological and behavioral impacts of SSC and duration on adult and juvenile salmonids. Newcombe and Jensen (1996) developed several empirically based models on the impacts of SSC on salmonids based on 80 published research studies. They developed a scale of “severity of ill effects” on the physiology and behavior of salmonids, ranging from 0 to 14, with 0 = no effect; 7 = moderate physiological effect, habitat degradation and impaired homing; and 14 = 80 to 100% mortality.

Based on data tables in Newcombe and Jensen (1996), severity indexes were calculated for various rainfall, average SSC, peak SSC, and duration values for storm events in Coal Creek. Two different tables were used from Newcombe and Jensen (1996). The first table was based on empirical data but only partially completed the matrix, requiring estimation from the closest neighbor value. The second theoretical matrix used a mathematical model to fill in missing data gaps in the empirical model. Both values are shown in Table 5.2 below.

Table 5.2. Suspended sediment concentration (SSC) severity index values for different rainfall and SSC events in Coal Creek. Average and peak SSC based on MFM, unpublished water quality data. Severity indices based on Newcombe and Jensen (1996).

24-Hour Rainfall	Average SSC	Peak SSC	Duration	Severity Index (Empirical)	Severity Index (Theoretical)
1 inch		100 mg/L	1 hour	4	5
1 inch	50 mg/L		14 hours	5	6
2 inch		600 mg/L	1 hour	4	6
2 inch	200 mg/L		14 hours	6	6
3 inch		2000 mg/L	1 hour	6	7
3 inch	500 mg/L		14 hours	8	7

During the month of April, when average Ozette River streamflow is still around 400 cfs, SS inputs from Coal Creek would normally be diluted by flow contributions from the Ozette River. Dilution of 50% of the SSC would have a negligible influence on the predicted effects on sockeye salmon at the concentration levels estimated to occur following the 2-inch storm event. More severe potential effects during the month of April would likely have a lower severity index due to the effects of dilution.

From May to August when lake level is typically low, no or very limited dilution from the Ozette River would be expected, because high intensity rainfall events usually reverse the flow of the Ozette River (during low lake level periods) and Ozette River flow is made up almost entirely of Coal Creek discharge. Severity indexes estimated from data tables in Newcombe and Jensen (1996) indicate that for moderately common storm events (10% to 3% probability of occurrence on any given day from May to August) in Coal Creek near Ozette, moderate behavioral and physiological stress could occur for both juvenile and adult sockeye.

Effects could include moderate physiological stress (6); moderate habitat degradation and impaired homing (7); and major indications of physiological stress and poor condition (8). However, the proportion of the population exposed to any given event is low (<6%). During the month of May, no more than 7.5% of the smolt and 6% of the adult populations are expected to encounter SSC predicted to result in moderate physiological stress. The proportion of the adult population expected to encounter SSC that results in moderate physiological stress is lower for June (~4.8%), July (1%), and August (<<1%). Cumulatively, approximately 12% of the population on average would be exposed to SSC expected to result in moderate physiological stress.

The effects of SSC on salmonids presented in Newcombe and Jensen (1996) should be used with caution, as most of the empirical data used for the synthesis was conducted in a controlled environment (laboratory flumes and tanks). Different studies used different combinations of sediment particle size caliber to create desired sediment concentrations and in some studies sediments may have been cleaned and washed of heavy metals or other material naturally found in streams. The particle size distribution making up the concentrated sediment suspended in water is extremely important in terms of effects on live salmonids and habitat in real streams (Newcombe and Jensen 1996). Larger suspended particles and more angular particles typically have greater impacts on physiology, while smaller particles have a greater impact on behavior (e.g., site distance and feeding). In addition, laboratory studies do not address synergistic effects of SSC (e.g., effects on predation, disease, temperature stress).

During relatively small events in Coal Creek, suspended sediment samples typically consist of silt and clay. As discharge magnitude and turbulence increases, a larger percent of the suspended sediment load consists of fine sand particles, as indicated by dozens of water samples filtered for SSC. In lower Coal Creek, abundant fine sand is readily observable in bar deposits, in overbank deposition on the floodplain, and in bar deposits at the confluence with Ozette River (see Sections 4.3.4 and 4.3.6.1). Examination of these sand particles from SSC samples under a microscope shows them to be quite angular and un-rounded. Future angularity measurements are needed from additional suspended sediment samples from all Ozette tributaries.

The size and angularity of suspended sediment particles coming from Coal Creek may partially explain field observations of increased significant physiological and behavioral stress on Ozette sockeye adults during migration. On June 11, 2000 approximately 2.3 inches of rainfall occurred in 24 hours (3.3 inches in 48 hours) while sockeye mark and recapture studies were being conducted in the Ozette River. Coal Creek was carrying high levels of suspended sediment into the Ozette River; the water was extremely turbid. Following the storm event in Coal Creek and the Ozette River, sockeye were noted as being "covered in silt" and an unspecified number were observed bleeding from the gills. Note that observers could not differentiate between silt and fine sand. While data from Newcombe and Jensen (1996) suggest this event would have a severity index of approximately 7, field observations indicate that the severity index was greater than 8. Gill abrasion is also influenced by water temperature (Newcombe and Jensen 1996), with increased abrasion during higher temperatures, which are observed during the later half of the adult sockeye migration into Lake Ozette.

In addition to biological effects, sedimentation can affect sockeye habitat in the Ozette River. Section 4.3.6 (Ozette River Hydrology) outlines the hydraulic and hydrologic influences of sediment deposition in Ozette River from Coal Creek sources. The bar controlling lake outflow and Ozette River discharge was once described as a "cobble riffle" (USGS, unpublished discharge measurement notes 1976-1979), while today the riffle contains very few cobble particles and is dominated by sand and small gravel. Fine sediment deposition has aggraded the bar upstream of Coal Creek by approximately 1 foot (Figure 4.38 and Figure 4.39; also see Section 4.3.6), which has altered both lake level fluctuations and Ozette River discharge (Section 5.3.2.2). Altered discharge output into Ozette River has reduced the quantity of water during critical adult sockeye migration periods, especially during the later half of the run (Section 5.3.2.2). In addition, aggradation of the hydraulic control of Lake Ozette has altered the fluctuations of lake levels, with slightly increased lake levels in the summer period. However, the exact impact of this more recent change on sockeye beach spawning habitat is unknown, especially in comparison to larger alterations to the lake's hydraulics and level variability (Kramer 1953; Herrera 2005).

5.3.4 Predation

Aquatic mammal and piscivorous fish predation on juvenile and adult sockeye in the Ozette River is well documented in the upper river, near the lake's outlet. Juvenile sockeye are preyed upon by a host of predators in the Ozette during their emigration in spring. Known predators in the Ozette River include river otters, seals, northern pikeminnow, and cutthroat trout. Additional potential predators include birds (e.g. bald eagles, osprey [*Pandion haliaetus]*, and mergansers[*Mergus spp.*]) and terrestrial mammals. No studies have been conducted exclusively focusing upon potential impacts of predators at the lake's outlet or in the Ozette River during the smolt emigration period.

During the summer of 2000, adults entering the Ozette River were captured in the estuary using a trap. Sockeye were handled, examined for scarring, tagged, and then released. It was found that 32.9% (27/82) of the sockeye captured in the estuary had scars associated with predation events. Fish were then recaptured going into Lake Ozette and reexamined to determine the rate of in-river scarring. Gearin et al. (2002) determined that the incidence of scarring increased from the lower river trapping site in the estuary by 10.7%. However, their sample size was small, as only 82 sockeye were trapped and released. Potentially more important than the findings showing increased in-river scarring, is the fact that only 50% (41) of the sockeye captured in the lower river could be accounted for entering the lake. Only 30 tagged sockeye were recaptured at the upper trap. Three tagged fish that were not recaptured at the Ozette counting weir were later recaptured on the beaches (eight fish were assumed to have lost their tags based on tag loss estimates). These data suggest that some fish may have delayed their upstream migration into the lake until after the trap was removed. The trap was removed 10 days after the last fish trapped in the lower river were tagged and released. Gearin et al. (2002) concluded that the 50% of sockeye missing from the upper river were either removed by predators in the river, died from other sources of mortality, escaped without being detected through the weir, or passed into the lake after the weir and trap were removed.

As described in Section 3.1.1, the mean transit time for tagged sockeye from the estuary to the upper counting weir was 65.2 hours for the 28 sockeye tagged and recaptured in 2000 (range 17-154 hrs). Based on these transit times, sockeye are vulnerable to predation in the river for nearly three days on average. Gearin et al. (2002) concluded that the proportion (43.6%) of sockeye with predator related scarring entering the lake was "*a cause for concern.*" A comparison of this rate to other scarring rates summarized for Pacific Northwest salmon stocks in NMFS (1997) indicates that it is among one of the highest rates observed in all other California, Oregon, and Washington predation studies. However, the total sample size of the 2000 Ozette River study was small. Time-lapse video data collected between 1998 and 2004 also included notes on sockeye scarring. From 1999 to 2003, sockeye scarring rates ranged from 5.5% to 10.6% (n=8,470;Table 5.3).

Table 5.3. Time-lapse video sockeye scarring rates for return years 1999 through 2003 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d).

Return Year	Time-Lapse Video Sockeye Scarring Rate	Number of Sockeye Viewed for Scarring
1999	10.6%	138
2000	7.7%	2,506
2001	5.7%	1,351
2002	7.0%	2,724
2003	5.5%	1,751

These data are limited to observations that come from imagery of one side of the sockeye transiting the viewing chamber. The top, bottom, and right hand side of the sockeye are seldom captured on video. During RY 2000, sockeye scarring was detected using time-lapse video, which revealed that 7.7% (192/2506) of sockeye had scars likely inflicted from pinnipeds (Haggerty 2005c). Sockeye were viewed for scars during RY 2000 when they were temporarily held in a 4-by-8-ft trap to examine for tags. These fish were not handled, but were visually examined in the river; not all scarring was detectable using this method. A total of 237 of 822 (28.8%) sockeye had visible scars and/or wounds. Scarring rates were 3.7 times higher for fish visually examined while held in the small trap as compared to those viewed using time-lapse video. Scarring rates were 5.7 times higher for fish that were examined by actually handling the fish than those detected using the time-lapse video data. Given this fact, the actual sockeye scarring rates are likely 3 to 6 times higher than those reported using time-lapse video data; actual scarring rates could easily average 30-60%. In addition to direct predation mortalities, unsuccessful predation events resulting in open wounds and lesions likely decrease the fitness of adult sockeye and make them more susceptible to disease during the protracted 3- to 9-month lake holding period. Fraser River researchers have found that sockeye salmon blood clotting capabilities decline at temperature exposures of 18-21°C and that some sockeye may die by bleeding to death from small cuts and lesions (Hinch 2005).

5.3.4.1 Predators

5.3.4.1.1 Harbor Seals (Phoca vitulina)

Harbor seals are frequently observed in the lower river but are less common in the upper river (Gearin et al. 1999; Gearin et al. 2002). The number of seals using the upper Ozette

River and Lake Ozette is unknown. Gearin et al. (2002) concluded that the number of harbor seals that frequent the Ozette River appears to be low (2-4 animals), but that even this low number could potentially impact Lake Ozette sockeye. No harbor seal population census data exist, but detailed observations of seals have been recorded and summarized during predation observation field work (see Gearin et al. 1999; Gearin et al. 2000; Gearin et al 2002) and sockeye enumeration and trapping activities from 1998 through 2004 (see Haggerty 2004a; Haggerty 2005a-d). No direct predation events on sockeye smolt by harbor seals have been documented in the Ozette River.

During return year 1998, a total of 7 seal observations were made at the weir. Five observations were made by visual observers and 2 were detected on time-lapse video footage (Haggerty 2005d). In 1998, detailed notes were not included with the seal observation data, so it is unknown how many of the observations were actually predation events, but at least one event included a sockeye mortality (Gearin et al. 2002). In 1999, both time-lapse video and visual observers were used to enumerate sockeye transiting the weir (Haggerty 2005d). Time-lapse video observers detected a total of 7 seals transiting the weir between May 5 and June 3, 1999 (Haggerty 2005d). During this same time period visual observers stationed at the weir made 24 seal observations, including three documented predation events[16] resulting in the deaths of two sockeye salmon (MFM unpublished weir data). Visual observers detected three times as many seals as the time-lapse video. Many of the visual observations were of seals “working” the front of the weir versus transiting the weir (MFM unpublished weir data). All seal observation events during 1999 occurred at dark or near twilight hours (Haggerty 2005d and MFM unpublished weir data).

During RY 2000, both underwater time-lapse VCR and visual observer data were collected at the Ozette weir. However, in 2000, the two data types are not paired observations. Observer data were collected during trapping operations on the opposite side of the river from the time-lapse video system. Seals were observed a total of 40 times in 2000 (Haggerty 2005c). Only two of the observations were classified as predation events, and neither appeared to result in the direct morality of the sockeye. Seal activities near the weir and trap occurred almost exclusively at night or twilight (>90% of observations; Haggerty 2005c). Table 5.4 includes all seal observations made at the Ozette River counting weir for return years 1999 through 2004. Seals appear to behave differently around the weir than otters and likely have a lower chance of being captured on video preying on sockeye than otters. Almost all of the time-lapse video observations of seals are transits through the weir. Visual observers stationed at the weir observed seals working the face of weir and in these cases there would be no chance for the camera to detect this behavior. Almost all seal activities were observed between dusk and dawn when lake level was greater than 32.5 ft at the ONP staff gage. Figure 5.21 depicts the RY 2002 seal observations at the weir, peak sockeye migration time period, and lake level. These data indicate that seal abundance in the upper river is controlled primarily by streamflow conditions and not sockeye abundance. It is presumed that at

[16] Sockeye counting weir mammal predation events were defined as events when sockeye salmon were clearly observed being chased, clawed, bitten, or carried off by predators.

flow levels corresponding with lake levels below 32.5 feet, migration conditions in the Ozette River preclude seals from entering the upper river.

Table 5.4. Summary of harbor seal activity at the Ozette River counting weir for RY 1999 through 2004 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d; MFM unpublished data).

Return Year	Total number of seal observations from time-lapse VCR data	Total number of seal observations made by visual observers	Total number of predation events observed	Total number of sockeye observed killed by seals
1999	7	24	3	2
2000	34	6	2	0
2001	8	0	0	0
2002	40	na	0	0
2003	0	na	0	0
2004	7	na	0	0

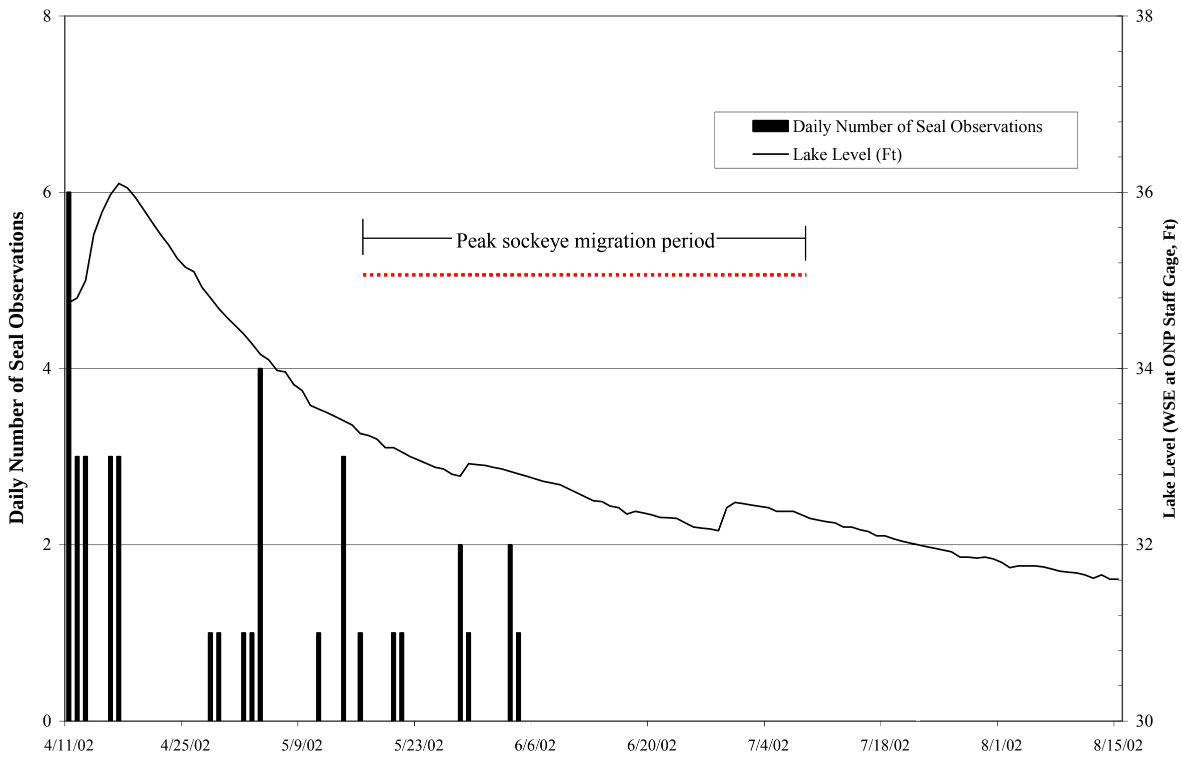

Figure 5.21. Comparison between 2002 daily number of seals detected by time-lapse VCR, lake level, and peak sockeye migration period (modified from Haggerty 2004a).

5.3.4.1.2 River Otters (Lutra canadensis)

As described above in Section 5.2.2.1.3, river otters are abundant in the Ozette River; the river provides ideal otter habitat. The number of river otters using the Ozette River is unknown. River otters can be observed during all hours but primarily hunt during twilight and darkness. River otters have been observed preying upon both juvenile and adult sockeye at the counting weir and during smolt trapping operations. Prior to RY 2004, over 99% (105/106) of observed otter-adult sockeye predation events occurred at night or during twilight hours (from Haggerty 2004a, 2005a, 2005b, 2005c, 2005d). During RY 2004, more than 22% of the otter-adult sockeye predation events occurred during daylight hours (6/27; MFM unpublished weir data). The fact that otter predation mostly occurs at night makes it extremely difficult to accurately quantify the number of sockeye preyed by otters in the Ozette River (Gearin et al. 2002). Gearin et al. (1999) collected and examined 40 river otter scats along the Ozette River during June 1998. The majority of these samples were collected from within 200 meters of the adult counting weir. Prey content analysis from these scat samples revealed that crayfish were present in higher frequencies than any other prey type. Figure 5.22 depicts the frequency of common prey types from river otter scat samples. Additional prey items detected in river otter scats include snails, clams, lamprey, insects, isopods, smelt, amphibians, and spiders. The only salmonid prey items that could positively be identified by species were Chinook and coho salmon; no sockeye remains could be positively identified.

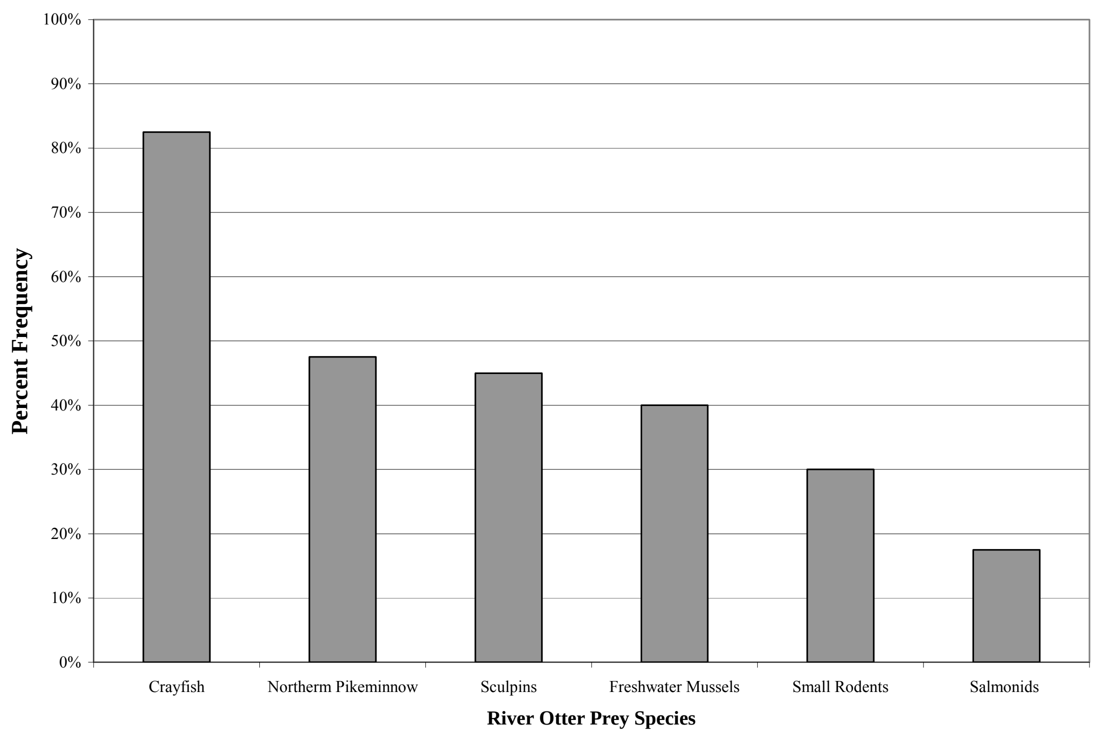

Figure 5.22. Frequency of most common prey identified from river otter scats collected in the Ozette River during June 1998 (n=40; modified from Gearin et al. 1999)

Gearin et al. (2002) concluded after 3 years of pinniped monitoring in the Ozette River that they were unable to quantify or give a reasonable estimate of the number of sockeye preyed by river otters. River otter observations made during adult sockeye enumeration work have been collected since 1998 and show what appears to be a steady increase in the number of observed otter-related sockeye mortalities (Figure 5.23). River otters have been observed killing more sockeye in the Ozette River than any other species of predator.

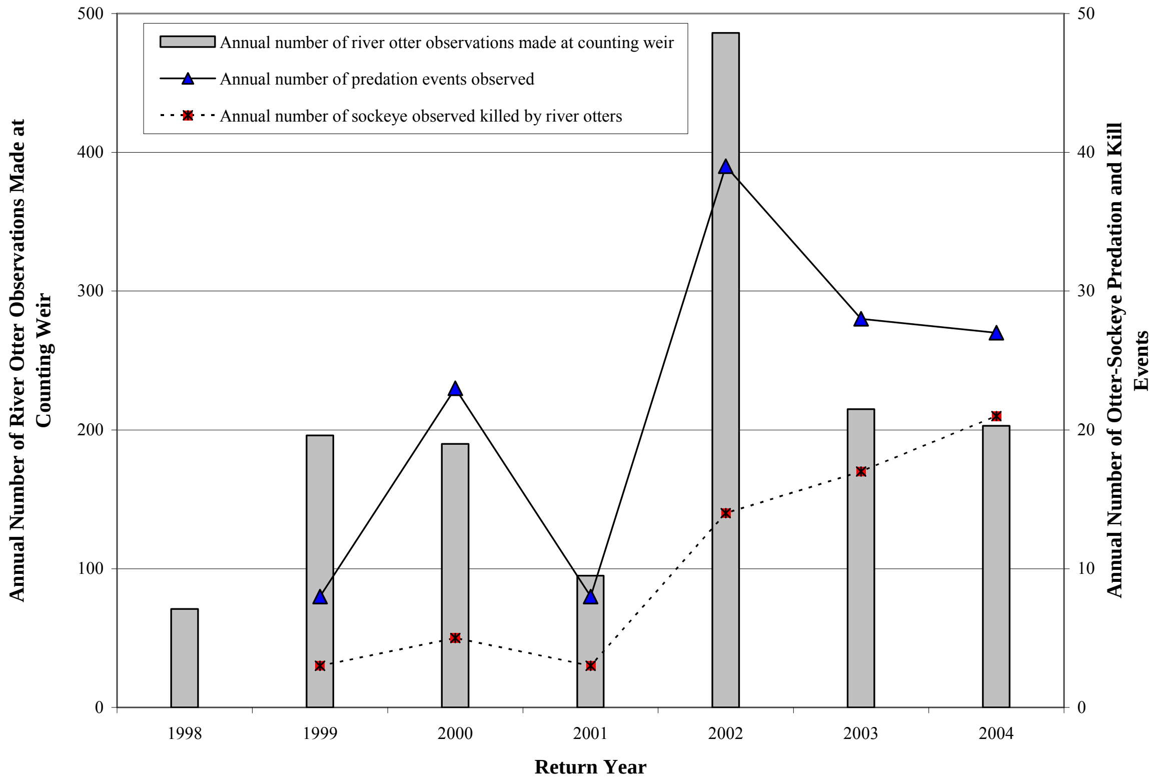

Figure 5.23. Annual number of otters, sockeye-otter predation events, and number of otter-sockeye kill events observed at the Ozette counting weir from 1998 through 2004 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d; MFM unpublished data).

5.3.4.1.3 Northern Pikeminnow (Ptychocheilus oregonensis)

A description of the Lake Ozette northern pikeminnow population is included in Section 2.2.8. Northern pikeminnow are known to prey upon juvenile sockeye in the Ozette River. Documentation of predation within the river is limited to observations from adult trapping, tagging, and weir enumeration work, as well as sockeye smolt trapping. Time-lapse video data collected at the Ozette counting weir from 1999 through 2004 indicates that northern pikeminnow are present in the upper river during the entire sockeye smolt emigration period. Smolt trapping data collected from 2001 to 2004 also clearly demonstrate that these two fish species occur together throughout the emigration period. Cumulative daily northern pikeminnow and sockeye and coho smolt counts for 2004 are shown in Figure 5.24. Approximately 61% of all sockeye smolt captures occurred during an 11-day period from May 3 to May 14, 2004. Similarly, 54% and 46% of the northern pikeminnow and coho smolt captures were during this same time period.

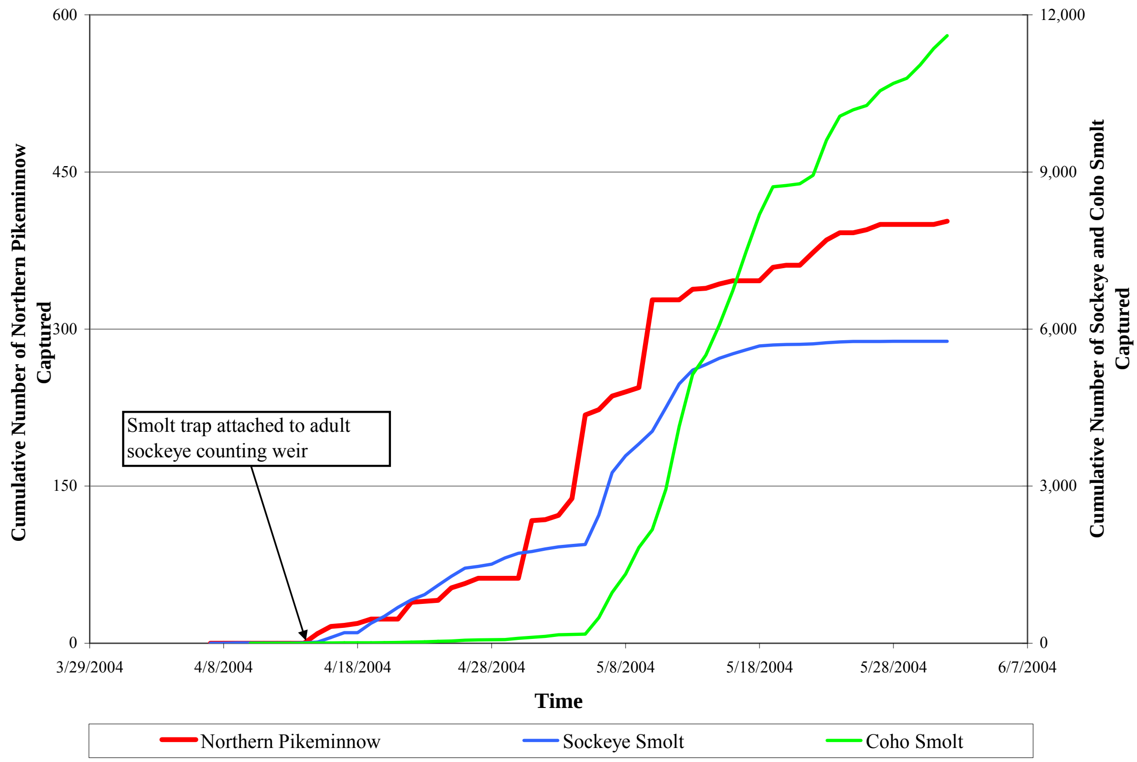

Figure 5.24. Cumulative northern pikeminnow and sockeye and coho smolt captures in the Ozette River, Spring 2004 (source: MFM, unpublished data).

Northern pikeminnow captured in the smolt trap are typically sampled for stomach contents. Sockeye smolt mortalities during trapping in 2002, 2003, and 2004 were 131, 12, and 57 sockeye smolts respectively (Crewson 2003; Peterschmidt 2005). Almost all sockeye smolt mortalities resulted from predation by northern pikeminnow (Crewson 2003; Peterschmidt 2005). Northern pikeminnow captures during this same time period were 394, 31, and 403. The smolt trap was not deployed until after the peak of the sockeye smolt emigration in 2003, when only 31 northern pikeminnow were captured. The total number of northern pikeminnows utilizing the Ozette River during the sockeye smolt emigration period is unknown. Smolt trap counts of northern pikeminnow are only a fraction of the total population. No estimates of the number of sockeye smolts consumed by northern pikeminnow in the Ozette River are available. Large numbers of northern pikeminnow can be seen throughout the upper Ozette River during spring, but their frequency and distribution downstream is unknown. These large schools of northern pikeminnow can be seen during daylight areas swimming from bank to bank in what appears to be a foraging behavior upstream of the adult counting weir.

5.3.4.1.4 Cutthroat Trout (Oncorhynchus clarki)

A description of the Lake Ozette cutthroat population is included in Section 2.1.6. Cutthroat trout are known to prey upon juvenile sockeye in the Ozette River. Smolt trap and adult sockeye weir data indicate that cutthroat trout likely occur in only limited numbers in the Ozette River during the smolt emigration period. Stomach contents of adult cutthroat trout captured during smolt trapping operations have not been examined. Predation work conducted by Beauchamp et al. (1993) and Dlugokenski et al. (1981) did not include cutthroat captured in the Ozette River. Beauchamp et al. (1993) found that within the lake, per capita consumption of salmonids by cutthroat trout was 25 times greater than that for northern pikeminnows.

5.3.4.1.5 Introduced Fish Species

Currently there are five known non-native fish species in the Ozette watershed: tui chub, American shad, yellow perch, largemouth bass, and brown bullhead. Within the Ozette River, largemouth bass are the only non-native predator of sockeye smolt. Largemouth bass are infrequently observed in the Ozette River and they are thought to occur in low numbers. A few largemouth bass have been captured during trapping activities during the sockeye smolt emigration period.

5.3.4.1.6 Terrestrial Mammals

Black bears (*Ursus americanus)*, cougars (*Puma concolor*), bobcats (*Lynx rufus*), raccoons (*Procyon lotor*), and other terrestrial mammals may also prey upon juvenile and adult sockeye in the Ozette River. However, conditions in the Ozette River during adult and juvenile migration periods are far from optimal for terrestrial mammals. No direct observations could be found of terrestrial mammal predation on juvenile and adult sockeye salmon in the Ozette River.

5.3.4.1.7 Avian Predators

Avian predators are assumed to prey upon sockeye smolt in the Ozette River, although we were unable to find any documentation of this. Osprey, bald eagles, hooded mergansers (*Mergus cucullatus*), common mergansers (*Mergus merganser americanus*), belted kingfishers (*Ceryle alycon*), and great blue herons (*Ardea herodias*) are all predators found in the Ozette River. Hooded mergansers are commonly observed fishing near the lake outlet during the smolt emigration period. Bald eagles have been observed taking adult sockeye-sized salmonids in the lower river and adult sockeye in the lake. Bald eagles or other large birds likely prey upon adult sockeye within the Ozette River. However, the overall number of adult sockeye killed by birds is thought to be low.

5.3.4.2 Factors Affecting Predation

5.3.4.2.1 LWD Removal

Logjam removal and habitat conditions in the Ozette River are discussed in detail in Sections 1.5.5 and 4.3. The removal of LWD from the Ozette River is thought to have significantly affected habitat conditions within the river. Currently, large stretches of the river are devoid of functional LWD. Pool frequency and refuge cover is low or nonexistent in wood-starved reaches. Haggerty and Ritchie (2004) examined 1,963 pools within the Ozette watershed and found that high quality pool habitats were most often associated with LWD obstructions and that the larger the LWD forming the obstruction, the larger and more complex were the pools and pool habitats associated with them. During multiple snorkel surveys of the entire Ozette River, the majority of pools were found to be formed by wood. Pools formed by key-piece-sized wood were generally 1 to 3 meters deeper than the channel upstream or downstream, where LWD was lacking. Habitat simplification in the Ozette River is believed to increase both juvenile and adult sockeye salmon's susceptibility to predation. Logjam removal may also have affected the streamflow conditions in which large predators such as seals can navigate into the river. Frequent, large logjams may have hindered seal migration up the river during lower flows. Currently seals are not observed using the upper river when the lake level drops below 32.5 ft; it is assumed that upstream passage is limited during levels lower than 32.5ft.

5.3.4.2.2 Increases in Aquatic Mammal Abundance

Regional factors affecting increases in pinniped abundance are described in Section 5.2.2.2.1. Additional factors such as the change in jurisdiction (from State to NPS) of the Ozette River and Lake Ozette are thought to have also increased the number of river otters within the watershed. No river otter census data are available, so no population trends have been documented. Also note that harbor seal use of the upper Ozette River and Lake Ozette was not documented until the late 1980s. Use of the upper river appears to have increased during the last 15 or 20 years.

5.3.4.2.3 Abandonment of Ozette Village

See Section 5.2.2.2.2

5.3.4.2.4 Changes in the Streamflow Regime of the Ozette River

There are two main factors that appear to have affected streamflow in the Ozette River: 1) wood removal from the Ozette River, which has been shown to lower lake stage, and 2) a shift in the stage-discharge relationship, which appears to be attributable to recent (during the last 20 years) sediment deposition and accumulation near the confluence with Coal Creek. Lower stage and/or discharge have been shown to affect daily sockeye entry timing into the lake. During periods of lower discharge, sockeye enter the lake primarily during twilight or darkness, but the majority enter during daylight hours when lake stage is above 33.5 feet (Figure 3.5). In order to fully understand the impact of wood removal on spring and early summer lake stage in comparison to potentially altered lake inflow discharge, a more dynamic hydrologic model is needed to account for all water budget attributes in the watershed. Nonetheless, lower stage and/or flow results in a higher percentage of sockeye transiting the upper river during time periods of known increased predator activity. In addition, it is thought that sockeye are more easily preyed upon by river otters during periods of lower flow.

5.3.4.2.5 Decreased Sockeye Abundance

See Section 5.2.2.2.3.

5.3.4.2.6 Changes in Lake and Fisheries Management

Changes in lake and fisheries management have the potential to increase the abundance of certain predators. For example, implementation of fishing regulations requiring release of coastal cutthroat trout may increase the abundance of cutthroat trout in the lake. Increased numbers of cutthroat trout in the lake would likely result in increased mortality on juvenile sockeye, as cutthroat trout are the primary predators of juvenile sockeye rearing in Lake Ozette (Beauchamp et al. 1995). While it is not possible to estimate the total impacts on mortality to juvenile sockeye and reductions in adult run-size, conservative estimates indicate regulation changes could result in a 10-22% reduction in the annual abundance of returning adult sockeye salmon

In 1953, the NPS acquired the strip of land between the west shore of the lake and the ocean. In 1976, it acquired the lake and a narrow strip of land around its perimeter (Meyer and Brenkman 2001). Jurisdiction of Lake Ozette was transferred from the State to the National Park Service. The transfer of jurisdiction resulted in regulations prohibiting trapping and hunting in and adjacent to the lake and river. This has likely resulted in an increased number of river otters within the watershed.

5.3.4.2.7 Ozette Sockeye Weir and Smolt Trapping Operations

Over the course of the last 80 years, weirs, weighted nets, traps, and fyke nets have all been used to enumerate adult and juvenile sockeye in the Ozette River. During almost all of the last 27 years, some form of a channel-spanning weir has been placed across the Ozette River during the peak of the adult sockeye migration. During the late 1970s and early 1980s, a weighted net and counting board were used to enumerate migrating adults. More recently a rigid weir has been used. Each year since 2001, an adult counting weir and rotary screw trap have been installed and operated just downstream of the ONP footbridge on the Ozette River (Figure 5.25). The width of the river at the weir location is approximately 100 ft (30m). Depth typically averages 3 to 6 feet at the time of installation. The weir is composed of several hundred metal tubes supported by large aluminum brackets that are held in place by a series of wooden tripods. During some years, half-inch *Vexar* is placed along the upstream face of the weir to increase smolt trap efficiency.

Figure 5.25. Photo looking from the right to the left bank of the Ozette River, showing the counting weir, adult trap, and rotary screw trap.

Sockeye smolts can pass between the narrow openings between weir pickets, but numerous hours of observation indicate that some smolts are reluctant to pass between these openings. Schools of smolts, all facing upstream, will swim from side to side upstream of the weir until they either swim into the smolt trap, pass downstream through the adult sockeye opening, or turn downstream and swim between the pickets. Sockeye smolts can be vulnerable to predation when they encounter the weir and are unable or unwilling to find a route downstream. Schools of northern pikeminnow can be observed upstream of the weir attempting to eat emigrating sockeye and/or other species of juvenile salmonids.

When sockeye smolt are captured in the screw trap they are temporarily held in a live box. While in the live box, smolt are vulnerable to predation by northern pikeminnow and cutthroat trout also captured in the live box. Measures have been taken in the design of the live box to minimize predation impacts by including a predator exclusion zone within the live box. Observed sockeye smolt mortalities during trapping in 2002, 2003, and 2004 were 131, 12, and 57 sockeye smolts respectively (Crewson 2003; Peterschmidt 2005). Almost all sockeye smolt trap mortalities documented resulted from predation by northern pikeminnow (Crewson 2003; Peterschmidt 2005). During trapping from 2002 through 2004, it is estimated that only 5 to 18% of the total sockeye smolts emigrating downstream during the trapping season were captured and held in the live box.

Adult sockeye migrating into the lake are especially susceptible to predators as they transit the weir. The weir acts as a bottleneck to migrating sockeye; harbor seals and river otters appear to use the weir as an aid in hunting. Seals and otters have frequently been observed working the face of the weir, swimming back and forth across the river in search for sockeye. One interesting note is that 92% of all successful otter-sockeye predation events in return years 2000-2004 were observed when lake levels were between 33.2 and 32.0 feet, even though 48% of sockeye migrated outside of this lake level range. Also, more than 95% of all successful predation events observed have been during nighttime or twilight. The proportion of the sockeye run migrating during daylight hours has been shown to decrease as lake level and streamflow decline (see Section 3.1.1). It appears that the degree to which the weir and trapping operations increase adult sockeye salmon susceptibility to predation increases as lake level declines.

5.3.5 Directed Sockeye Harvest

Currently there is no directed sockeye harvest occurring in the Ozette River. For more information regarding directed sockeye harvest, see Section 5.2.3. In the Ozette watershed no fisheries are conducted during the sockeye run in which sockeye are harvested or captured as bycatch. A review of punch card returns and projected harvest estimates (1964-2004) indicates that very little if any sockeye harvest occurred prior to restrictions limiting harvest. Only eight salmon of undefined species are estimated to have been harvested within the migration timing of sockeye between 1964 and 2004.

5.3.6 Disease

No systematic monitoring of sockeye health in the river occurs. Observations of infections and fungus growth are occasionally included in weir observation notes, but no systematic inventory data are collected. During trapping in RY 2000, 899 sockeye were visually examined for external tags and physical condition. Less than 1% of the sockeye transiting the weir had visible fungal growth. However, at least some individual sockeye have been observed with severe external infections, and these likely die before reaching the spawning grounds (see Section 5.4.6).

5.4 LAKE OZETTE

Lake Ozette sockeye use the lake during several life history phases: adult holding (3.1.2); adult sockeye beach spawning and egg incubation (3.1.4); sockeye fry emergence and dispersal (3.1.6); and juvenile freshwater rearing (3.1.8). These life history phases in the lake are the focus of the limiting factors discussion presented in Section 5.4. Degraded and altered shoreline sediment conditions (4.2.1), hydrology and lake level (4.2.5), water quality (4.2.3), food availability (4.2.4), predation, competition, disease, hatchery impacts, and directed sockeye harvest are all factors that have been evaluated to determine the degree to which each factor currently or in the past has limited sockeye salmon survival and productivity in Lake Ozette.

5.4.1 Watershed Hydrology and Lake Level

The hydrology of the Ozette watershed and Lake Ozette is complex and controlled by several variables, which can be affected by natural and human-caused factors. As described in Section 5.3.1.2, logjams in the upper one mile of the Ozette River can exert a major hydraulic influence on lake stage. Wood removal beginning with the onset of homesteading (1890s) and continuing until the mid-1980s is thought to have significantly affected lake levels. Herrera (2006) linked channel incision in the lower reaches of lake tributaries to base level lowering of Lake Ozette. Herrera (2005) was unable to determine the precise amount that low, median, or peak lake levels have declined or changed from pre-settlement conditions. Instead they define a range of wood loading scenarios and predict resultant lake stages for a predefined period of existing lake stage and discharge data. Lake stage data from October 15, 2004 through January 30, 2005 were used to model of effect of different wood loading scenarios on lake stage during the beach spawning period (Figure 5.26).

This simulation suggests that mean water surface elevations during the modeled spawning period can vary by up to 4.1 feet, depending on wood loading conditions within the Ozette River. Current wood loading conditions relative to a completely jam-free river result in a mean lake level increase of 0.8 feet during the modeled spawning time period. The wood loading condition of the upper Ozette River before the onset of wood removal operations is unknown. Herrera (2005) suggests that historical conditions were within the 200-foot spacing, 60% blockage and 500 foot, 80% blockage range, based on maps, photos, and descriptions in Kramer (1953). Results predict that mean lake level during the modeled spawning period with current wood loading conditions is 1.5 to 3.3 feet lower than under historical wood loading conditions (Figure 5.26). These predictions correspond well with channel incision observations of approximately 3 feet (1 meter) observed in Ozette tributaries by Herrera (2006).

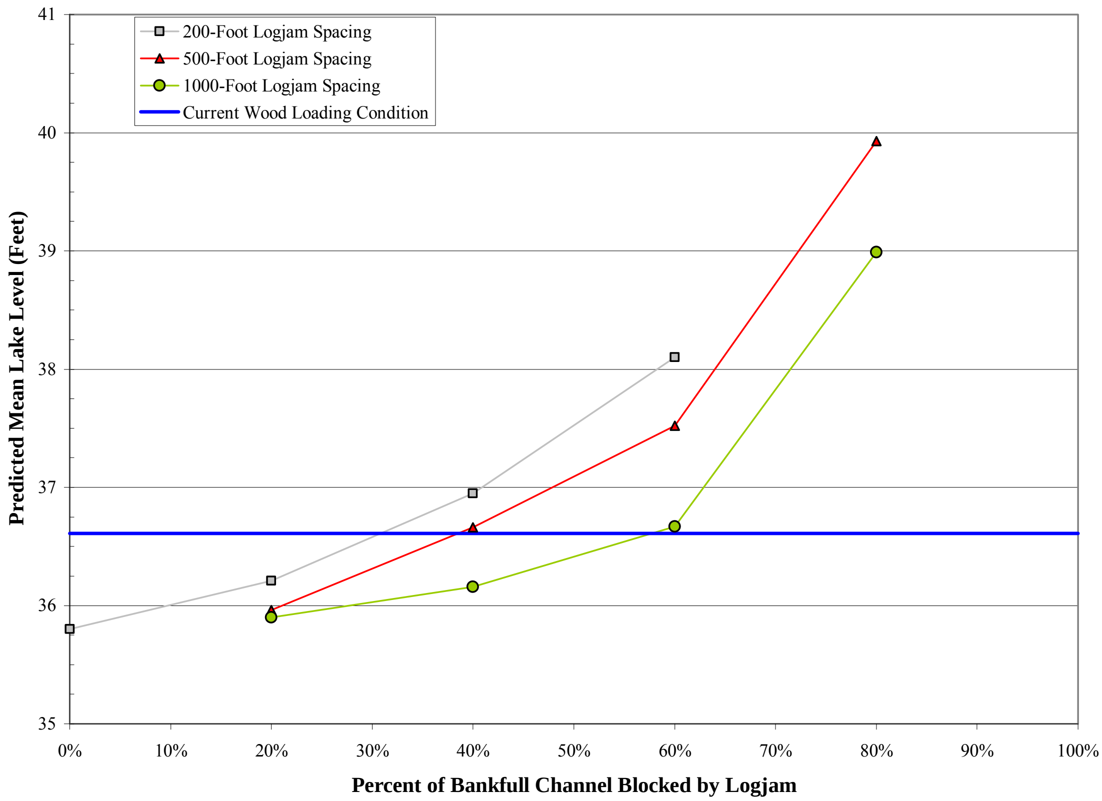

Figure 5.26. Comparison of observed mean lake level for October 15, 2004 through January 30, 2005 and different wood loading scenarios in the Ozette River and their corresponding predicted mean lake levels (modified from Herrera 2005). Note that this predicted mean lake level was for the modeled spawning period (October 15, 2004 to January 30, 2005), and does not correspond to the long-term measured mean lake level of 34 feet (Section 4.3.5).

Collectively, the findings of Herrera (2005, 2006) strongly suggest that mean lake level during the beach sockeye spawning period has been lowered by 1.5 to 3.3 feet. Lower mean lake levels would directly result in decreased beach spawning area (see Section 5.4.2.2.2). Potentially even more importantly, long-term lake level changes associated with Ozette River logjam removal could affect the quality of beach spawning gravels utilized by spawning sockeye. Herrera (2005, 2006) suggest that lowered lake levels could have a significant influence on the ability of vegetation to colonize the shorelines in spring and summer months. They conclude that changes in winter lake levels associated with high wood loading in the Ozette River could help to reduce or eliminate plant colonization and persistence along the portions of the shoreline once thought to be used by spawning sockeye salmon.

It still remains unclear how long-term lake level changes associated with LWD removal or land use effects on hydrology (Section 5.5.1) may affect seasonal lake level changes. It is hypothesized that wood removal at the outlet (lower sustained lake levels) and increased inflow discharge (temporarily elevated lake levels) have together increased the variability of lake level changes during the spawning and incubation season.

5.4.1.1 Seasonal Lake Level Changes

Seasonal lake level changes are known to directly result in sockeye redd dewatering. This occurs when sockeye spawn in November, December, and January at elevations along the beaches that become exposed by lowering lake levels before incubation and emergence. Redd desiccation has been observed or noted as occurring during several of the years when spawning ground surveys have been conducted (Dlugokenski et al. 1981; MFM unpublished spawning ground surveys). Only one year of spawning ground survey data exists for which any quantification of redd desiccation can be calculated. Redds were mapped during the RY 2000 spawning season and a total of 7 redds (~3% of redd surface area) at Olsen's Beach were deposited above the lake stage at which emergence was projected to occur. Redd elevation data were not collected at Allen's Beach during these surveys.

The relationship between redd dewatering and embryo survival for lake spawning sockeye is unclear. Since many sockeye spawning on Ozette beaches appear to select sites with upwelling associated with springs and seeps, some dewatered sockeye eggs may survive to hatching. If subsurface pathways through interstitial spaces to open water of the lake exist, survival to emergence may be possible in dewatered redds. However, high fine sediment levels observed in most beach spawning locations suggest that dewatered egg survival may be low. Peak spawn-timing, depth of spawning, and lake level at emergence are all important factors that influence the degree to which redd desiccation will occur. Years with early high lake levels (November and December) that coincide with peak spawn timing followed by lower than average late-winter and early-spring months likely result in more significant redd desiccation events (e.g. WY 1990; 1992; 1998). It is unclear what effect the long-term role of LWD removal or land use effects on hydrology has on timing or rate of seasonal lake level changes.

5.4.2 Spawning Gravel Quality and Quantity

The quantity and quality of beach spawning gravels in Lake Ozette are known to have declined significantly from their historical conditions to present. Reduced spawning gravel quantity and quality appear to be *key* limiting factors affecting the success of beach spawning sockeye in Lake Ozette. The degree to which habitat quantity has been reduced has not been quantified for the entire lake shoreline. The degree that habitat quality has been reduced has also not been quantified, due to the complexities required to quantify changes in habitat quality. Habitat quality reduction varies by site; for example, the entire Umbrella Beach spawning area has been covered by several acres of fine sediment deposition and no longer provides suitable habitat. Herrera (2006) collected bulk sediment samples at five sites along the mouth and delta and more than 50% of the substrate was composed of fine sediment less than 0.85 mm diameter.

Other potential spawning areas have been reduced by vegetation colonization, varying from small-scale increases in vegetation, to entire beach segments colonized by shrubs and grasses (adjacent to areas currently used by spawning sockeye). In general, high levels of fine sediment (<0.85 mm), vegetation encroachment and colonization of spawning gravels, reduced numbers of suitable spawning habitats, and changes in lake levels during spawning and incubation are thought to be the primary factors that have reduced spawning gravel quality and quantity. Detailed information regarding current beach spawning habitat conditions is included in Section 3.1.4 and 4.2.1.

5.4.2.1 Spawning Gravel Quality

During incubation, salmonid eggs require sufficient water flow to supply egg pockets with oxygen and carry away waste products (Bjornn and Reiser 1991). Water circulation through salmon redds is a function of redd porosity, permeability, and hydraulic gradient (Bjornn and Reiser 1991). Fine sediment that settles into redds during the egg incubation period can impede water circulation and fry movement, which can result in decreased egg-to-emergence survival (Bjornn and Reiser1991). Studies throughout the Pacific Northwest have found that increased levels of fine sediment (<0.85mm) in spawning gravels decreases egg to emergence survival (Cederholm et al. 1981; Bjornn and Reiser 1991; McHenry et al. 1994). Measured levels of fine sediment collected during fall of 1999 and 2000 on Olsen's and Allen's beaches averaged 25% fines less than 0.85mm (n=56; gravimetric processing method). Fine sediment levels in spawning gravels are highly variable on both beaches.

Egg basket studies conducted during the winter of 2000 and 2001 on Olsen's Beach indicate that egg to emergence survival is low (Crewson 2002). In 2001, eyed sockeye eggs were incubated in Olsen's Beach cleaned and uncleaned gravel inside egg baskets buried at 15 sites along the beach for 21 days. No statistically significant differences in survival were measured between cleaned and uncleaned gravel. Egg survival in uncleaned gravel baskets averaged 14.3% (0.23 stdv; n=15). Egg survival in cleaned gravel baskets averaged 10.6% (0.095 stdv; n=5). Median egg survival measured in 2001 on Olsen's Beach was 2% for uncleaned gravel and 8% for cleaned gravel (median =7% for all samples). Cleaned (n=5) and uncleaned (n=2) samples were positioned at two sites. Egg survival in the uncleaned gravel was 0% and 10.6% in the cleaned gravel.

Hatchery incubated eggs in cleaned and uncleaned gravel had survivals of 99.8% and 61.2% respectively (Crewson 2002). Eggs were also incubated in Jordan egg incubators above the lake bottom adjacent to Olsen's Beach in 2001 and survival was very high (99.4%). High egg survival in Olsen's Beach cleaned gravels incubated in the hatchery and high egg survival in artificial incubators incubated above the gravel on the beach, coupled with low survival of eggs in cleaned and uncleaned gravels incubated in the beach substrate, strongly suggest that incubation conditions in beach substrate are very poor and the source of the mortality observed during the study. Intermediate survival (62%) of eyed eggs incubated in uncleaned Olsen's Beach gravel in the hatchery suggest that fine sediment plays a significant role in egg mortality. These data also strongly suggest that other factors also contribute to reduced survival (e.g. vegetation, upwelling, inter-gravel flow). Green egg to fry survival rates based on egg basket studies suggest that survival rates range from 45-0%, averaging less than 1% (based on a spawning distribution pattern similar to basket placement, constant mortality rate throughout the incubation period, zero egg retention in spawners, 100% fertilization, no predation, and no redd superimposition). Dlugokenski et al. (1981) used a hydraulic sampler to obtain eyed eggs from a portion of a single redd on Olsen's Beach to examine early egg survival conditions. They found that survival to eyed stage was 47% for the single redd sampled and concluded that this was within a comparable range of natural production in other sockeye systems. Several factors that have the potential to affect incubation conditions in spawning gravels have been identified and include: high levels of fine sediment and increased sediment production in tributaries and delivery to lake spawning sites, vegetation colonization of gravels, decreased sockeye population size, upwelling (inter-gravel flow), and lake level alterations.

5.4.2.1.1 Factors Affecting Spawning Gravel Quality

Factors affecting spawning gravel quality are examined in more detail in this section.

5.4.2.1.1.1 Sediment Production and Delivery from Tributaries

Delivery of fine sediment to the lake from tributaries has increased during the last 50 to 100 years (Herrera 2006). Current sediment production rates are estimated to be more than three times greater than pre-disturbance production rates (Herrera 2006). Herrera (2006) attributes the recent (last 50 years) increased sediment production mainly to forest practices (primarily roads and clear-cutting) and channel incision associated with LWD removal from the Ozette River. While it appears that increased sediment production in lake tributaries has resulted primarily from land-use activities, it is not fully understood to what degree these increases have affected the <u>remaining</u> utilized beach spawning habitats. Historically utilized beaches, such as Umbrella Beach, have a clear link between sediment source and delivery. Dlugokenski et al (1981) documented the creation of a sand bar off of the mouth of Umbrella Creek, and the siltation of sockeye spawning grounds at Umbrella Beach. McHenry et al. 1996 stated, "*Mass sedimentation from logging on private land has eliminated spawning habitat in Umbrella Bay [Beach].*" Herrera (2006) describes 5.7 acres of fine and coarse sediment aggradation between 1964 and 2003 at Umbrella Beach.

The following four figures (Figure 5.27 through Figure 5.30) are products of an ongoing GIS analysis of aerial photos from 1953-2006, due to be published in a research report to ONP in 2007 (Ritchie, unpublished data). Figure 5.27 illustrates the relationship between percent of old growth forest clear-cut and delta growth through time in the Umbrella

Creek watershed. A highly significant relationship (r^2=0.87; p<0.001) between percent old growth clear-cut and total delta growth was found (Figure 5.28). A highly significant relationship (r^2=0.95; p<0.001) between percent old growth clear-cut and proximal delta growth was also found (Figure 5.28). Figure 5.29 illustrates the relationship between road density and delta growth through time in the Umbrella Creed watershed. A highly significant relationship (r^2=0.88; p<0.001) between road density and total delta growth was found (Figure 5.30). A highly significant relationship (r^2=0.96; p<0.001) between road density and proximal delta growth was also found (Figure 5.30).

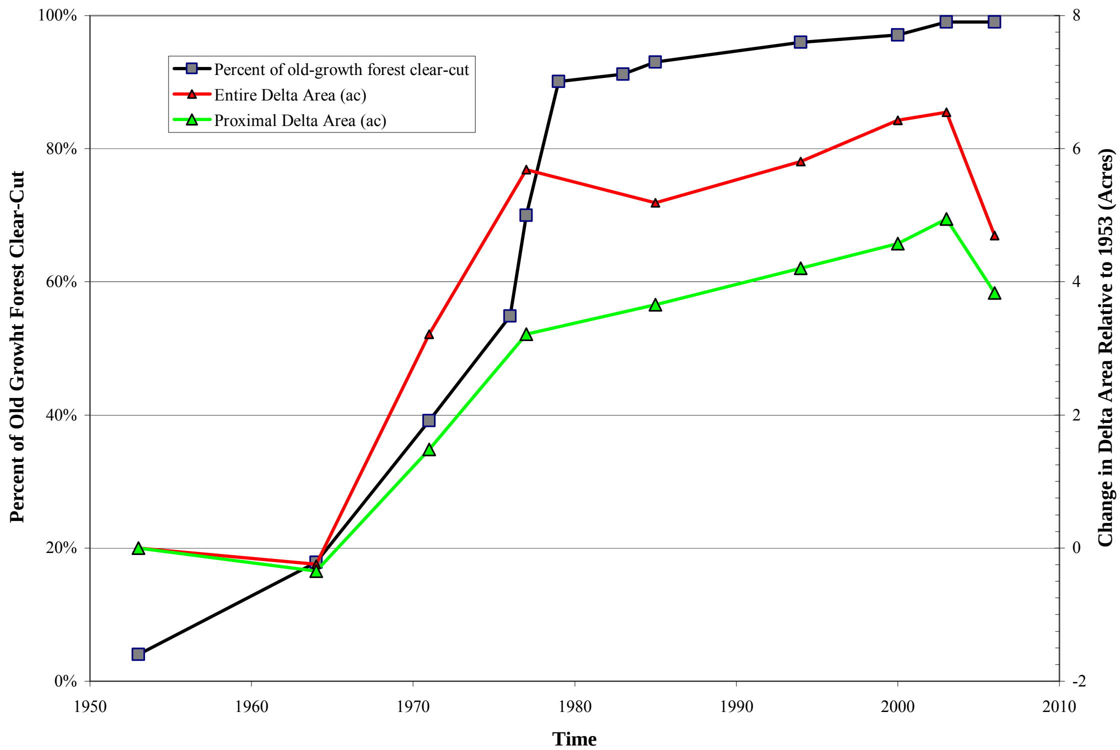

Figure 5.27. Percent of old growth forest clear-cut contrasted with total delta and proximal delta area change through time.

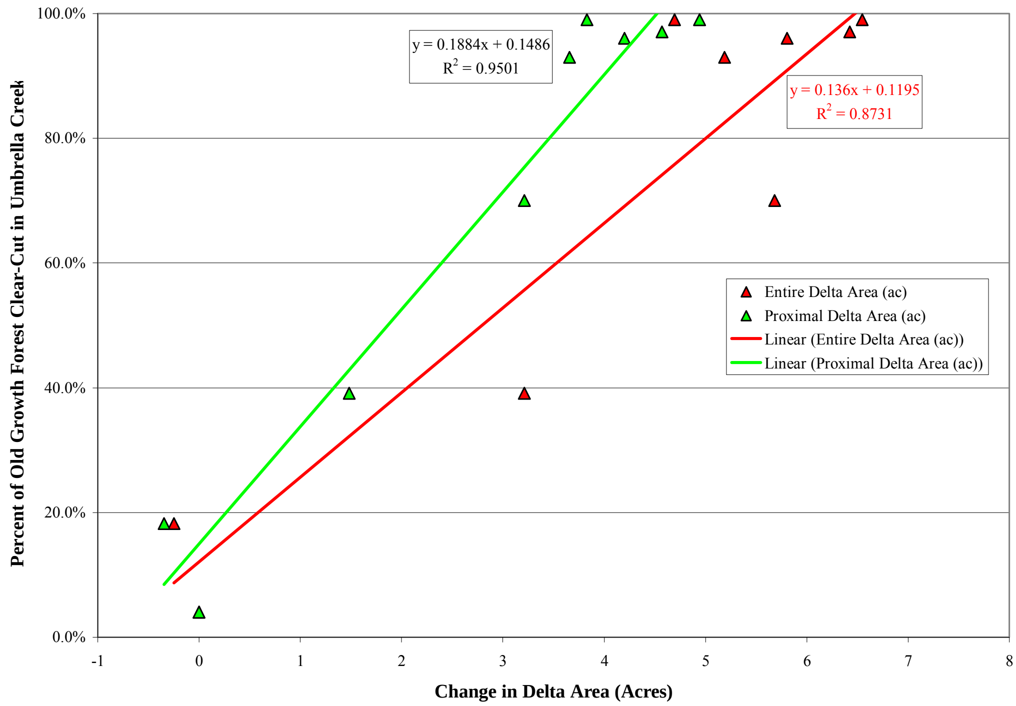

Figure 5.28. Relationship between percent old growth forest clear-cut and total and proximal delta growth for the Umbrella Creek sub-basin.

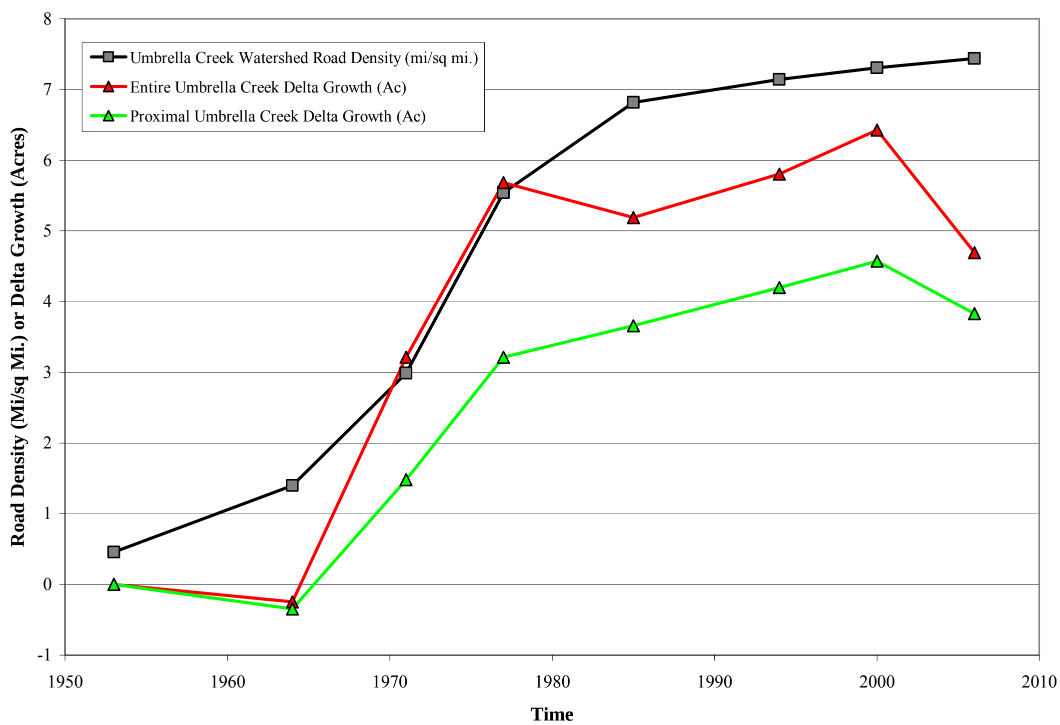

Figure 5.29. Umbrella Creek road density contrasted with entire and proximal delta growth through time.

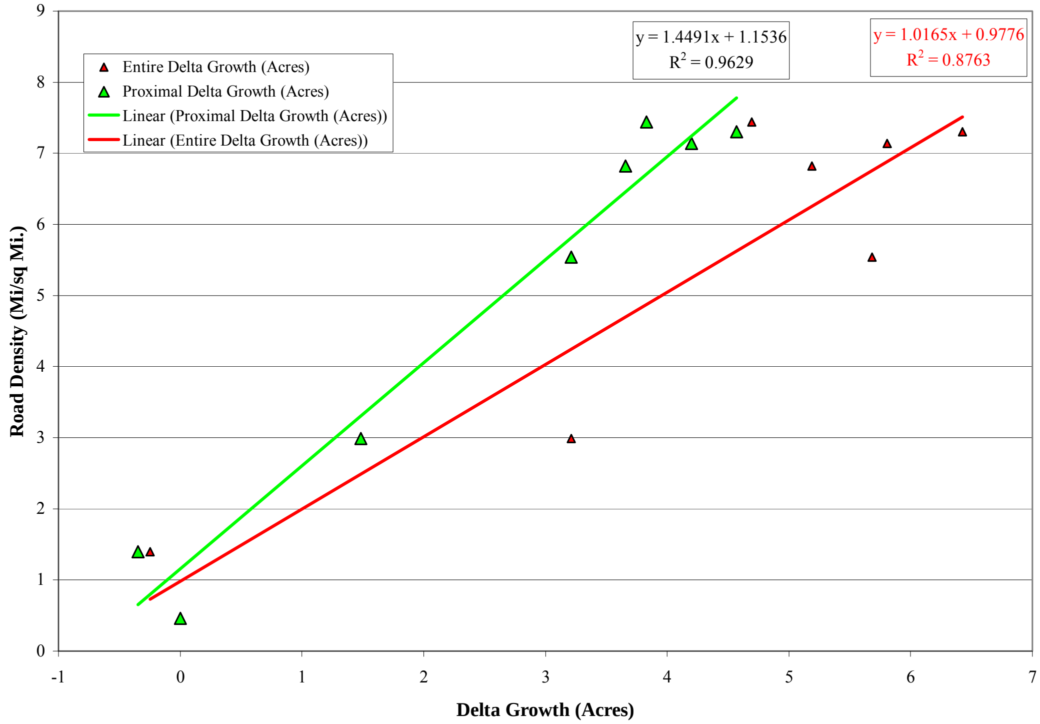

Figure 5.30. Relationship between road density and total and proximal delta growth for the Umbrella Creek watershed.

Sediment delivery from streams and slopes, combined with lateral lake shore transport, are the primary mechanism for fine sediment delivery to sockeye spawning habitat. Therefore sediment delivery would be expected to be highest close to sediment sources. This is interesting since the remaining beach spawning sites appear to be as far away from the main sediment sources (Umbrella Creek, Big River, and Crooked Creek) as possible and pre-existing habitat closer to these sources is no longer used for spawning (e.g. Umbrella Beach). It is highly unlikely that significant quantities of fine sediment from Umbrella Creek, Big River, and Crooked Creek are transported to Allen's or Olsen's beaches. The dominant transport direction is northward along the eastern shoreline of the lake, and both Allen's and Olsen's beaches are far south from these tributaries. However, fine sediment delivery to the lake also occurs from smaller lake tributaries near the remaining spawning beaches. No shoreline sediment routing models have been developed for Ozette, but general wind patterns are depicted in Figure 1.9 and generalized relative longshore transport vectors are shown in Figure 5.31.

Olsen's beach spawning areas are much closer to larger tributary sediment sources (i.e., Siwash, Elk, 20.0073) than Allen's Beach (i.e., Allen's Slough). The mouth of Elk Creek is within 280 feet (85 m) of the Olsen's Beach spawning area and the prevailing wind and sediment transport direction is toward the spawning area. Siwash Creek is within 1,250 feet (381 m) of Olsen's Beach and sediment transport and dominant wind direction is toward the spawning area. Unnamed tributary 20.0073 is within 900 feet (274 m) of Olsen's Beach and sediment transport and dominant wind direction is away from the spawning area. South Creek is located within 2.4 miles (3.8 km) of south Olsen's Beach. Sediment transport direction is generally north-northeast, but complex beach geography with north-west trending shorelines likely limit sediment transport to the northeast.

Streams near Allen's Beach include: Allen's Slough, West Shore Tributary 5, and West Shore Tributary 6. A few very small streams also enter the lake along Allen's Beach. Allen's Slough is approximately 2,700 feet (823 m) from the southern end of Allen's Beach. Allen's Slough is low energy; sediment transport and dominant wind direction are toward the east and north-east edge of Allen's Bay, away from the spawning area at Allen's Beach. Shoreline geometry suggests that only suspended sediment could be transported to Allen's Beach from Allen's Slough. West Shore Tributary 6 enters the lake along the north shore of Cemetery Point (see Figure 3.7). Shoreline substrate conditions are gravel and cobble near the confluence. West Shore Tributary 5 enters the lake 300 feet north of Allen's Beach. Fine sediment is the dominant substrate at the confluence and along the shoreline to the north. Sediment transport and dominant wind direction is away from the spawning area.

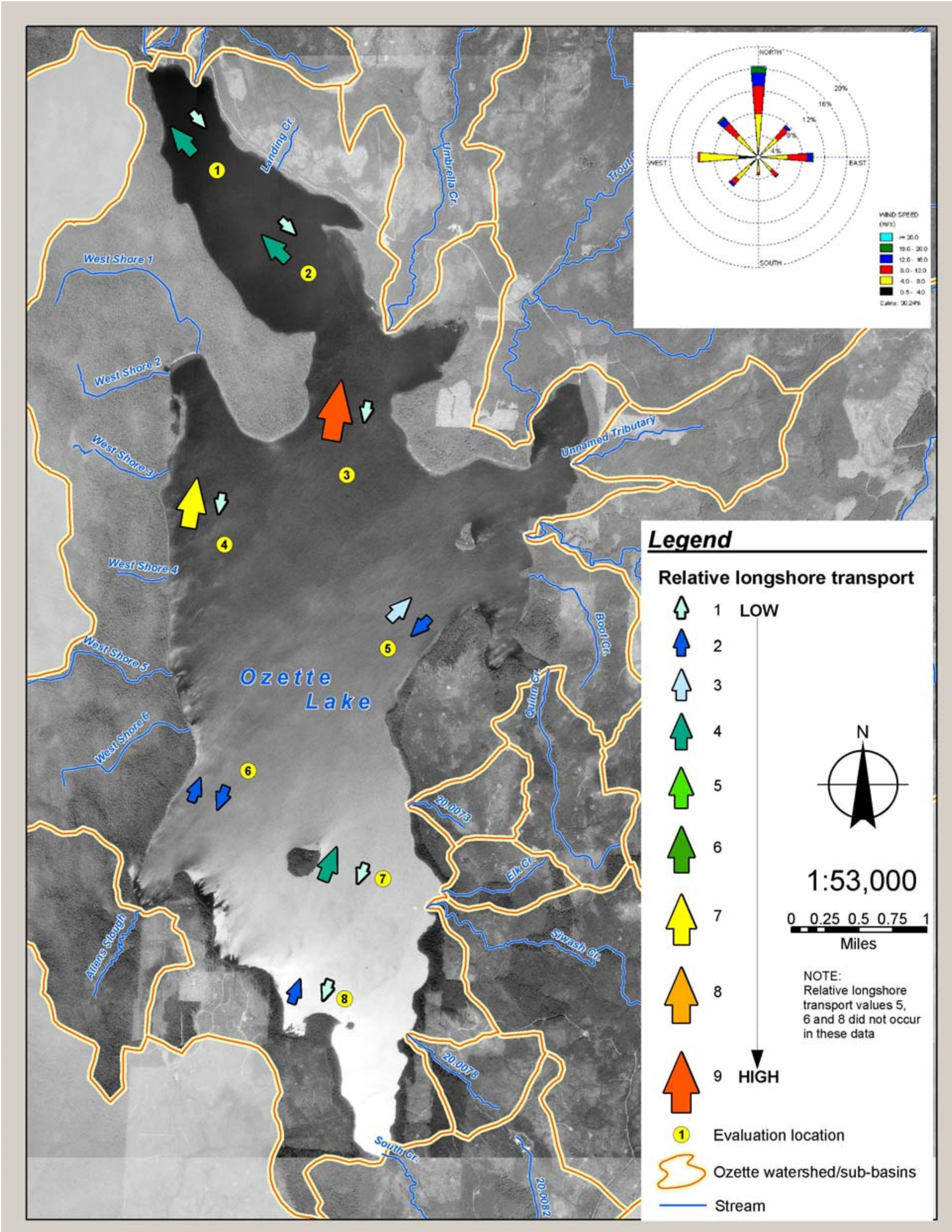

Figure 5.31. Magnitude and direction of dominant relative longshore transport for eight sites on Lake Ozette (modified from Herrera 2006)

Additionally, a small unnamed stream enters the lake just north of the base of the small spit. Sediment substrate in the vicinity of the confluence is composed entirely of fine sediment. Fine sediment along this segment of the beach truncates spawning habitat located to the south. The spit defining the boundary between Allen's Bay and the lake suggests that dominant long-shore drift direction at south Allen's Beach is southwest, toward Allen's Bay. A detailed investigation of shoreline sediment routing is recommended to determine sediment routing along the shorelines of the lake.

Fine sediment core sample data indicate that Olsen's Beach has slightly higher levels of fine sediment (n= 46, average 26.1%, range 7.0 to 72.7%) than Allen's Beach (n= 13, average 22.6%, range 4.6 to 44.3%). However, the sample size at Allen's Beach is relatively small and may not fully represent the diversity of substrate conditions at all the dispersed (and deep) spawning sites at Allen's. The core, concentrated, and dispersed spawning areas at Olsen's Beach appear to be well-represented by the 46 sample sites.

5.4.2.1.1.2 Small Spawning Population Size

The small beach spawning aggregations that have persisted during the last 30 years may have been reduced to levels incapable of sufficiently cleaning spawning gravels and maintaining vegetation-free spawning gravels. During the act of spawning, salmonids winnow fine sediment from spawning substrate (Kondolf et al. 1993). Lack of sufficient numbers of spawners could result in degraded habitat conditions, as well as increased levels of fine sediment within spawning gravels. In stream systems, fine sediment excavated from the substrate during spawning is transported downstream and out of the egg pocket. For mass spawning fish (e.g., chum [or sockeye]), gravel cleaning and coarsening at least temporarily (Peterson and Quinn 1996; Kondolf et al. 1993; Peterson and Foote 2000) reduces the fine sediment levels in the bed and redd (Kondolf and Wolman 1993; Kondolf et al. 1993; Moore 2006), increasing egg to fry survival. The reduction of mass spawning fish populations such as sockeye, resulting from other limiting factors (e.g. overfishing), has been hypothesized to create a negative feedback loop due to reduced gravel bed maintenance of fine sediment levels in lake or streams, or scour depths in streams (Montgomery et al. 1996).

No documented research on the effect of mass spawning sockeye on beach substrates was located during an exhaustive literature review. However, one point worthy of note is that many of the gravel samples collected where low levels (<10%) of fine sediment were recorded appeared to be in sites that were spawned in during the previous winter. The role of sockeye spawning on gravel quality maintenance is poorly understood but may be of particular importance on Ozette beaches and should not be overlooked as a limiting habitat factor. Moore (2006) determined that when habitat modification by salmon promotes their own success, there will be feedback between generations. Understanding whether recovery of a small population will be inhibited by lack of habitat maintenance is critical.

5.4.2.1.1.3 Colonization of Native and Non-Native Vegetation

Colonization of native and non-native vegetation along the lake shoreline may influence sediment particle size distribution along the spawning beaches. Ritchie (2005) and Herrera (2005, 2006) both found increases in shoreline vegetation during the last 50 years. Herrera (2005) determined that vegetation has substantially encroached along the lake shoreline as a result of the lowering of both winter and summer lake levels following large scale wood removal operations in the Ozette River. Vegetation colonization of the spawning gravels can decrease wave energy in and around the spawning gravels, which can result in increased fine sediment deposition. A positive feedback loop can develop between vegetation colonization and sediment deposition: increased sediment improves vegetation colonization, and increased vegetation further increases sediment deposition. The dense root networks of vegetation submerged in the winter act as excellent filters for trapping fine sediment and building up a soil layer over previous gravel bed surfaces. Furthermore, vegetation colonization that blocks or limits wave energy and wave-driven currents can negatively affect sockeye spawning in lake shore areas where sockeye are dependent on wave-driven currents for egg oxygenation.

5.4.2.2 Reduced Spawning Area

Suitable spawning habitat area in Lake Ozette has declined during the last 50 to 100 years. The historical spawning distribution of beach spawning Lake Ozette sockeye is not fully understood. Dlugokenski et al. (1981) observed sockeye spawning to the north of Umbrella Creek during surveys in the late 1970s, but no sockeye have been observed spawning there since (despite exhaustive surveys). Currently available spawning habitat along the beaches appears able to produce only a small fraction of the population abundance that is thought to have once occupied the lake. One reasonable explanation to limits affecting the beach spawning component of the population is loss of spawning area at extant spawning beaches, as well as the complete loss of some spawning aggregations (e.g. Umbrella Beach). Kemmerich (1939) describes Ozette sockeye spawning as occurring "*especially at the mouths of several creeks.*" Ozette sockeye are no longer observed spawning at creek mouths. The number of beach spawning aggregations that have been entirely eliminated remains unknown. The dominant spawning behavior of Lake Ozette sockeye described by Kemmerich (1939) is no longer observed. It is unknown whether sufficient habitat exists to initiate recovery of the beach spawning population without first rehabilitating additional spawning habitat. It seems unlikely that beach spawning population abundance can recover to pre-decline levels without increasing the number of beach spawning aggregations, as well as the quantity of suitable spawning habitat. Increased sediment production from tributaries, small spawning population size, and colonization of native and non-native vegetation have all acted as factors to decrease the area of suitable spawning gravel. Predicted changes in lake level following wood removal could also significantly affect suitable spawning habitat area. The cumulative effects of increased sediment production, changes in lake level, and vegetation colonization have reduced the suitable spawning habitat (above 31.5 ft MSL) area by more than 70% at Olsen's and Allen's beaches.

5.4.2.2.1 Increased Sediment Production in Tributaries

Increased sediment production in the Umbrella Creek watershed appears to be the primary factor responsible for the loss of the Umbrella Beach spawning aggregation (see Sections 5.4.2.1.1 and 5.4.2.1.1.1). While no direct measurements of past sediment production are available, indirect estimates of past and current sediment production strongly suggest that large-scale changes in sediment production (> 3 times pre-disturbance sediment production rates), storage, and transport have occurred during the last 50 years in Lake Ozette tributaries (Herrera 2006). Herrera (2006) estimates that delta growth between 1964 and 2003 was approximately 5.7 acres (23,000 m^2). Much of the delta growth described by Herrera (2006) was just north of the mouth of Umbrella Creek. This is the same area where spawning sockeye salmon were observed by Dlugokenski et al. (1981). Much of the new (post-1964) delta is now vegetated in shrubs, as is much of the older (pre-1964) delta, which contained little vegetation along the lake margins in 1964 (see Figure 4.7). Additional sediment input and delivery to the lake from other tributaries also may have resulted in spawning habitat losses. However, there are no confirmed sites other than Umbrella Beach where this is thought to have occurred.

5.4.2.2.2 Changes in Lake Level

Changes in Ozette Lake level associated with logjam removal in the Ozette River could have two main impacts on spawning habitat availability: 1) lower water surface levels in the lake (especially during the growing season) could influence the ability for vegetation to colonize spawning gravels, and 2) lower lake levels result in less spawning gravel habitat inundated during the spawning and incubation period. Herrera (2005, 2006) suggests that lowered lake levels could have a significant influence on the ability of vegetation to colonize the shorelines in spring and summer months. They concluded that associated winter lake levels with high wood loading in the Ozette River, coupled with wet season wind events, could help reduce or eliminate plant colonization and persistence along the portions of the shoreline once thought to be utilized by spawning sockeye salmon (see Section 5.4.2.2.3).

Collectively, the findings of Herrera (2005, 2006) strongly suggest that mean lake level during the beach sockeye spawning period has been lowered by 1.5 to 3.3 feet from historical levels. Lowered mean lake levels during the spawning and incubation periods directly result in decreased beach spawning area. Herrera (2005, 2006) was unable to fully quantify the percent of habitat lost due to lowered lake levels. Herrera (2005) estimated that a 3.3 ft (1 m) increase in mean lake level would result in 33 to 39 lineal feet of inundated beaches at Olsen's and Allen's beaches, respectively. These estimates were based on elevation data derived from LiDAR data and did not include WSE during the critical egg incubation period. In order to better understand and estimate losses to beach spawning habitat, the lowest water surface elevations during the spawning and incubation period (for existing conditions as well as under different wood loading scenarios) and beach geometry were plotted together for the core spawning area at Olsen's Beach (Figure 5.32). Projected incubation period was determined based on RY 2003 spawn timing and incubation duration based on average incubation temperatures. The lowest lake level during projected incubation period was based on continuous lake level measurements.

Core spawning area habitat losses were estimated based on wood loading conditions in the Ozette River of 200 ft jam spacing at 60% blockage and 500 ft spacing at 80% blockage. It was estimated that 700 sq ft (~11%) and 2,100 sq ft (~33%), respectively, of "new" spawning habitat would be usable under these wood loading conditions. It is important to note that beach geometry plays a critical role in estimating potential spawning habitat loss. Transects north and south of the core spawning area are plotted in Figure 5.33. Estimated losses for the south beach under presumed historical wood loading conditions ranged from 3 to 6 horizontal feet and 6 and 12 horizontal feet for the transect to the north. These estimates are significantly less than those presented in Herrera (2005). The beach geometry within areas surveyed at Allen's Beach are much more uniform than areas surveyed at Olsen's. Figure 5.34 depicts a typical beach profile at Allen's Beach contrasted with lowest stage observed during egg incubation and modeled lake stage for two wood loading scenarios in the Ozette River. Estimated spawning area loss for the 200 ft spacing, 60% blockage wood loading scenario is approximately 6 horizontal feet, and the estimated spawning area loss for the 500 ft spacing, 80% blockage is approximately 26 horizontal feet.

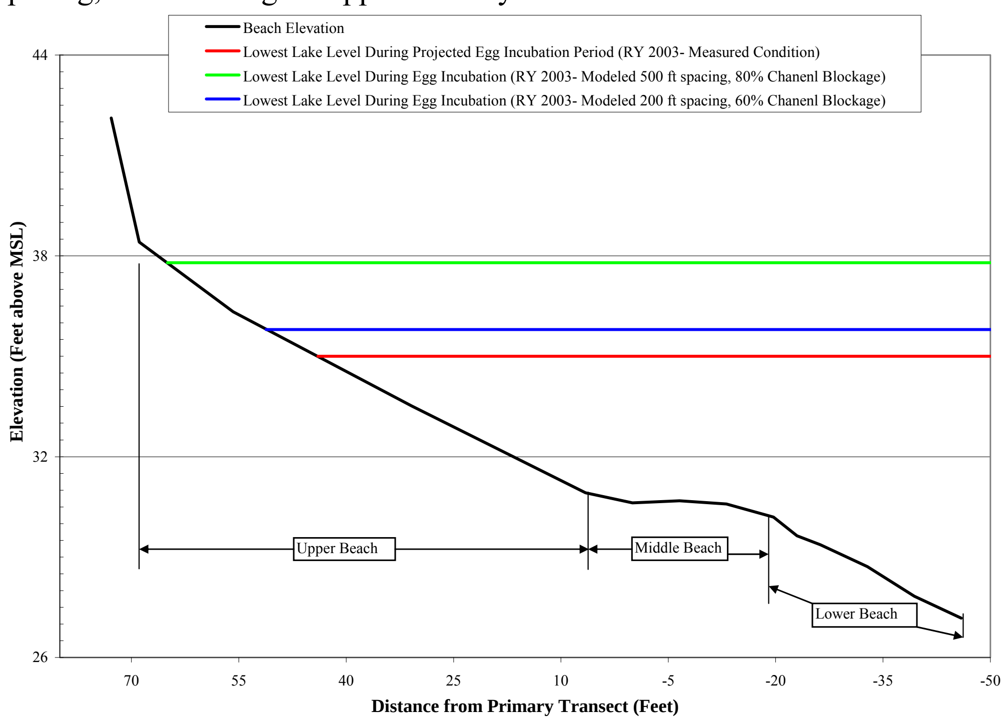

Figure 5.32. Comparison of lowest observed stage during projected incubation period at Olsen's Beach (RY 2003) core spawning area and modeled lowest water surface elevations during incubation for two Ozette River wood loading scenarios (based on Herrera 2005 model outputs).

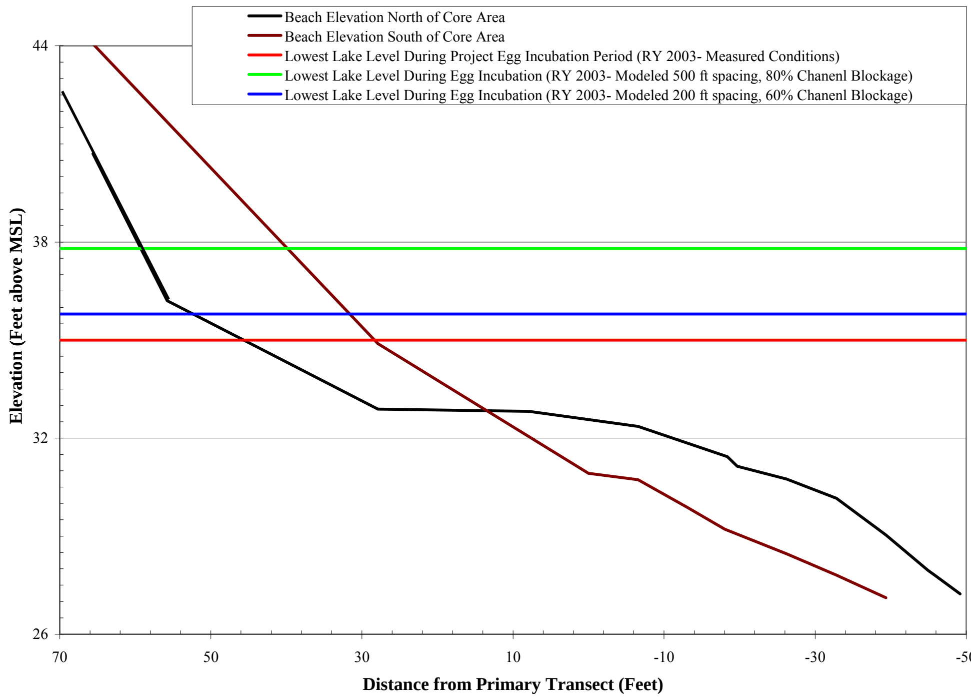

Figure 5.33. Comparison of lowest stage observed during projected egg incubation period at Olsen's Beach (RY 2003) spawning areas and modeled lowest WSEs during incubation for two Ozette River wood loading scenarios.

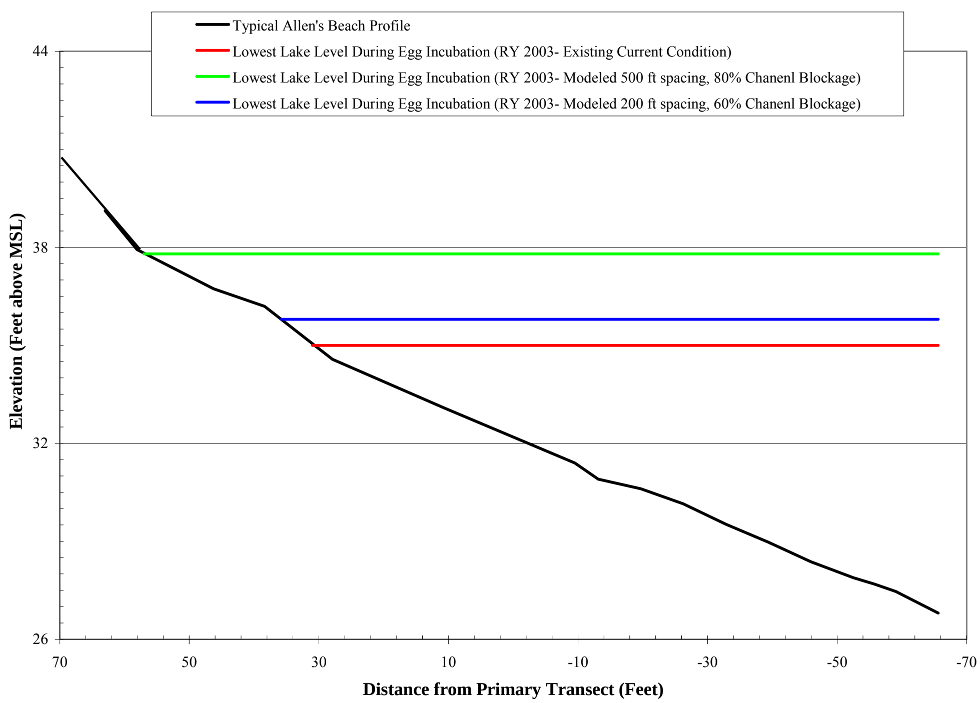

Figure 5.34. Comparison of lowest stage observed during projected egg incubation period at Allen's Beach (RY 2003) spawning areas and modeled lowest WSEs during incubation for two Ozette River wood loading scenarios.

5.4.2.2.3 Colonization of Native and Non-Native vegetation

Colonization of native and non-native plants in spawning gravel directly reduces the quantity of spawning habitat available for sockeye. Ritchie (2005), Herrera (2005, 2006), and Ritchie (2006) all found significant increases in shoreline vegetation during the last 50 years. Ritchie (2005) compared 45.6 km of shoreline from 1953 to 2003 (using geo-rectified aerial photos), and determined that 40.4% of the shoreline showed an increase in shoreline vegetation between 1953 and 2003. There was no change along 59.3% of the shoreline, and only about 0.3% of the shoreline showed a decrease in vegetation (see Section 4.2.1). Ritchie (2006) conducted a high resolution analysis of vegetation colonization of the shoreline from 1953-2003 (see Section 4.2.1). Ritchie identified 1,034,887 ft^2 (96,144 m^2) of unvegetated shoreline around the lake in 1953, and only 451,561 ft^2 (41,951 m^2) of unvegetated shoreline in 2003, a decrease of 56%. Ritchie found that unvegetated area at Allen's Beach dropped by 67%, from 125,645 ft^2 (11,673 m^2) in 1953, to 41,716 ft^2 (3,876 m^2) in 2003 (Figure 4.8). The length of shoreline analyzed was 8,670 ft (2,643 m). Unvegetated area at Olsen's Beach declined from 27,322 ft^2 (2,538 m^2) in 1953, to 9,343 ft^2 (868 m^2) in 2003, a decrease of 66% over 2,804 ft (855 m) of shoreline (Figure 4.9).

5.4.2.3 Other Factors Affecting Egg to Emergence Survival

Additional interrelated factors are believed to reduce egg to emergence survival along the spawning beaches. Redd superimposition on the spawning beaches is thought to significantly reduce the survival of earlier deposited eggs on the spawning beaches. The degree to which this is occurring is difficult to measure, but sockeye spawning on Olsen's Beach seem to be especially prone to multiple spawning events in the same location during the same season. As described in Section 3.1.4, during RY 2000, sockeye were observed spawning in the same location over an 89-day period, and over 90% of the redd surface area measured had been spawned-in multiple times during the spawning season. These observations provide additional evidence that suitable/preferred spawning area is limited. Since Ozette sockeye appear to prefer areas with springs and seeps for spawning, it is thought that alterations in the location, degree, and depth of upwelling could negatively affect beach spawning, although no such alterations have been documented. Also see Section 5.4.5 for more factors affecting egg to emergence survival.

5.4.3 Water Quality

Water quality data for Lake Ozette are presented in detail in Section 4.2.3. In general, water quality in Lake Ozette is thought to be negligible as a limiting factor for sockeye salmon at all life history stages in the lake with the exception of adult spawning. Turbidity (specifically suspended sediment) during spawning may affect sockeye salmon spawning on the beaches of Lake Ozette. However, the degree to which suspended sediment and turbidity affect spawners remains unclear. In historical spawning sites at the mouths of creeks (e.g. Umbrella Beach) suspended sediment concentrations are much higher (see Section 4.4.1.5; Figure 5.43) and the potential effects on sockeye more severe than at Olsen's and Allen's beaches, which are partially removed from the largest tributary inputs.

Meyer and Brenkman (2001) measured a large turbidity plume at the north end of the lake in March 1994. Turbidity in the middle of Swan Bay was 35 NTUs (higher than turbidity measured in Big River). High intensity storms that generate large floods and high SSC levels can generate long duration turbidity/SSC events in the lake. This increases the duration that sockeye salmon are exposed to high turbidity levels. For example, the December 15, 1999 flood resulted in high turbidity levels throughout the entire lake; visibility in the lake approached zero. Visibility remained poor (1-3 feet) for several weeks following the flood. Such high turbidity levels of long duration in the lake are likely to be caused by abundant clay or very fine silt, rather than sand input from the tributaries, which is more likely to be transported by wind-driven currents along the shoreline. In a review of the literature, Cook-Tabor (1994) cites several studies that reported negative effects on salmonids at turbidity levels of 15-30 NTU and gill tissue damage when exposed to turbidity levels of 25 NTU over 5-7 days. High turbidity and resulting poor visibility could affect mate selection efficiency and decrease efficiency in locating suitable spawning habitat, as well as decrease predator avoidance capability.

5.4.4 Food Availability/Competition

Sockeye prey composition and availability, as well as competition for prey in Lake Ozette, have been investigated in part or whole by Bortleson and Dion (1979), Dlugokenski et al. (1981), Blum (1988), Beauchamp and LaRiviere (1993), and Meyer and Brenkman (2001). Past surveys in Lake Ozette indicate that juvenile *O. nerka* occur at higher frequencies in the pelagic zone than all other fish species combined (Beauchamp and LaRiviere 1993). Approximately 94% of the fish >100mm (FL) caught in vertical gill nets in April 1991 were sockeye salmon pre-smolts or kokanee (Beauchamp et al 1995). In the summer months only 54% of the gill net catch was composed of kokanee salmon, but age 0 sockeye/kokanee salmon were not susceptible to gill net capture (Beauchamp et al. 1995). *Daphnia pulicaria* dominate the diet of juvenile *O. nerka* salmon throughout the year (Beauchamp et al. 1995). Benthic invertebrates, adult insects, and copepods comprised 7-46% of the adult kokanee salmon diets from late-summer through early-spring (Beauchamp et al. 1995).

Beauchamp et al (1995) estimated that juvenile sockeye and all year classes of kokanee consumed less than 1% of the monthly standing stock of *Daphnia pulicaria* > 1.0 mm in size, suggesting that food availability for rearing fish was not limiting *O. nerka* productivity. All researchers (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; Beauchamp and LaRiviere 1993), independent of methodologies, have concluded that Lake Ozette sockeye productivity and survival are not limited by food availability or competition.

5.4.5 Predation

Predation on sockeye salmon occurs during all life history phases within the lake. Sockeye salmon are preyed upon by a host of predators in the lake, including harbor seals, river otters, northern pikeminnow, cutthroat trout, sculpin, other native and non-native fishes, and various species of birds. Several studies have been conducted within the lake attempting to determine predation levels on sockeye salmon at various life history stages (Dlugokenski et al. 1981; Beauchamp and LaRiviere 1993; Gearin et al. 1999; Gearin et al. 2002). None of these studies was able to determine the number or proportion of sockeye salmon preyed upon at any life history stage. Additional observations and studies have also documented predation on sockeye salmon at different life history stages. Brief descriptions of sockeye predation by life history stage in Lake Ozette are included below.

A complete description of adult sockeye holding in Lake Ozette can be found in Section 3.1.2. During the period that adult sockeye hold in the lake, they are primarily susceptible to predation by river otters and harbor seals. Combined acoustic and radio tag studies were conducted with RY 2000 and RY 2001 adult sockeye salmon. Hughes et al. (2002) determined that the vast majority of RY 2000 tagged sockeye appeared to have died before spawning, near Rocky Point and off of the mouth of Umbrella Creek. Hughes et al. (2002) also found a similar pattern with RY 2001 tagged fish; they appeared to have died near Rocky Point, Preachers Point, Boot Bay, and off of Umbrella Creek. Hughes et al. (2002) speculated that predation may have played a role in the pre-spawning mortality of sockeye. Since most tags in fish that were assumed to have died prior to spawning could not be retrieved (because of depth), researchers were unable to confirm the cause of death. One RY 2000 CART tagged sockeye was recovered from Allen's Beach and it was determined to have been killed by a harbor seal (Hughes et al. 2002; Figure 5.35). Otter scat were collected during the summer of 2001 through 2003 to determine whether river otters were actively preying upon adult sockeye holding in the lake. These samples have not been fully processed, so results from this work are not yet available.

A complete description of sockeye spawning on Lake Ozette beaches can be found in Section 3.1.4. Beach spawning sockeye are preyed upon during spawning by river otters, harbor seals, and bald eagles (Gearin et al. 2002). Gearin et al. (2002) suggested that the majority of predation occurs at nighttime, based upon the very limited predation activity they observed during daylight hours while monitoring predation activities along the primary spawning beaches. Gearin et al. (2002) were unable to quantify the amount of predation occurring at the primary beach spawning sites because most predation occurs during darkness. They concluded that the primary spawning beaches were possibly the areas of most concern within the watershed with respect to adult sockeye predation, because sockeye on the spawning grounds are most valuable (with respect to reproduction) and vulnerable.

Sockeye are more vulnerable to predation along the beaches because they are in shallow water and often preoccupied by the act of spawning or redd defense. During RY 2000, an extensive effort was made to recover carcasses for a sockeye genetics study (see Crewson et al. 2001 and Hawkins 2004). During carcass recovery work it was noted that 47% (36 of 77) of sockeye carcasses recovered from Allen's Beach consisted only of heads (Hughes et al. 2002). Many of these appeared to be from fish in relatively good condition (see Figure 5.35) that may have been killed before or during spawning (Hughes et al. 2002).

Gearin et al. (2002) examined 27 of these carcasses and concluded that 52%, 33%, and 15% were from pre-spawners, spawners, and spawned-out sockeye respectively. Carcass recovery on Olsen's Beach the same year found that less than 10% of the carcasses recovered consisted of only heads (n>100; MFM, unpublished field notes). Gearin et al. (2002) examined 43 sockeye carcasses recovered from the beaches in RY 2000 and RY 2001 and judged that 84% were eaten by river otters and 14% by harbor seals. Predator delineation was based on inner-canine distance measurements from recovered sockeye. There is the possibility that sockeye preyed upon by seals were later scavenged by otters, which could affect the proportions reported by Gearin et al. (2002).

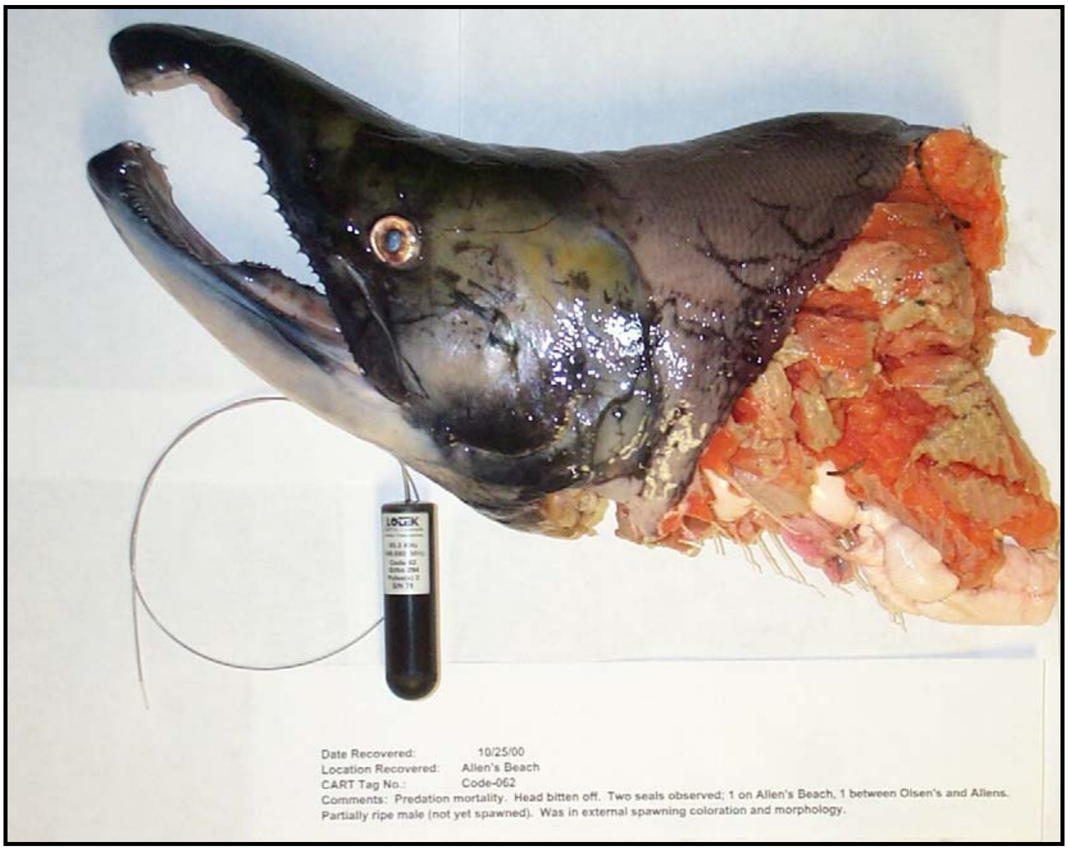

Figure 5.35. Pre-spawning predation mortality recovered from Allen's Beach October 25, 2000 (CART Tag No. 062; source: MFM photo archives).

Sockeye eggs incubating in redds constructed on the beaches are susceptible to predation by sculpin, cutthroat trout, and, potentially, river otters. No attempt to measure sockeye egg predation on the beaches has been conducted. However, sculpin and cutthroat trout have been directly observed preying on sockeye eggs. Foote and Brown (1998) determined that 16 to 32% of sockeye eggs deposited on spawning beaches studied on Lake Iliamna were preyed upon by sculpins. In addition to sculpin and cutthroat trout, sockeye eggs may also be preyed upon by aquatic insects. During egg basket studies conducted during the winter of 2000/01 at Olsen's Beach, leeches appeared to prey upon nearly all of the eggs within one of the egg baskets placed in beach substrate. Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in the nearshore environment of the beaches. Emergent sockeye fry are believed to quickly disperse from the beaches and enter the pelagic zone of the lake (Jacobs et al. 1996). No work has been conducted to estimate emergent sockeye fry predation along the beaches. Potential predators at this life history stage include sculpin (sp), northern pikeminnow, cutthroat trout, juvenile steelhead trout, juvenile coho salmon, yellow perch, and largemouth bass. Predator interactions at this early life history stage remain a data gap and it is possible that significant levels of predation occur in the vicinity of the spawning beaches.

A complete description of rearing by juvenile sockeye originating from Lake Ozette beaches can be found in Section 3.1.8. Both tributary and beach spawning populations of sockeye are vulnerable to predation within the limnetic zone of the lake. Within the limnetic zone, sockeye and kokanee are the predominant species present (Beauchamp and LaRiviere 1993). While the lake harbors a wide array of fish species, there is little spatial and temporal overlap between most species of potential predators (Beauchamp and LaRiviere 1993). The primary piscivores within the limnetic zone are northern pikeminnow and cutthroat trout (Beauchamp and LaRiviere 1993). Predation research within the lake has been unable to calculate the proportion of juvenile sockeye preyed on by limnetic piscivores. However, Beauchamp and LaRiviere were able to determine that 72% of the annual diet (by volume) of large (>300mm FL), limnetic northern pikeminnow consisted of age-0 and age-1 *O. nerka*. They also found that 40% of the diet of large (>300mm FL), limnetic cutthroat trout consisted of age-0 and age-1 *O. nerka* during spring and summer months.

5.4.5.1 Predators

5.4.5.1.1 Harbor Seals (Phoca vitulina)

Harbor seals are most commonly observed in the lake during fall and winter months, but seals will also enter during spring or early summer while following migrating sockeye up river. No harbor seal population census data exist for the lake, but detailed observations of seals have been recorded and summarized during predation observation field work (see Gearin et al. 1999; Gearin et al. 2000; Gearin et al 2002), sockeye spawning ground surveys, and CART tag tracking activities from 1998 through 2001. Harbor seals are believed to prey primarily on adult salmonids while in the lake. No direct predation events on juvenile sockeye in the lake have been documented.

Seal observation data for the lake is difficult to summarize for multiple years because of varying effort between years and differences in observers present and observation methods employed. The most comprehensive seal observation dataset was collected during fall and winter 2000. Gearin et al. (2002) spent a total of over 188 hours conducting pinniped predation observations at four key locations along the lake between November 2, 2000 and January 11, 2000 (Table 5.5). A total of 71.75 hours of observation spanning 19 days was conducted at Allen's Beach. During this time period, a total of five seals were observed along Allen's Beach; three of these seals appeared to be transiting the area; one was observed foraging along the shore; one was observed chasing a sockeye salmon (Gearin et al. 2002).

Table 5.5. Pinniped predation observer effort during return year 2000 sockeye spawning season at four key locations along Lake Ozette (Gearin et al. 2002).

Date	Allen's Beach (hrs)	Olsen's Beach (hrs)	Umbrella Creek (hrs)	Big River (hrs)	Total
11/2/00	3.75	2	1.75	0	7.5
11/3/00	3.75	2.25	1.75	0	7.75
11/7/00	0.5	1.25	0	0	1.75
11/8/00	5.75	3.25	1.5	1.75	12.25
11/9/00	3.0	3.0	4.5	1.0	11.5
11/14/00	4.75	5.25	3.7	0	13.7
11/15/00	7.5	2.95	3.0	0.5	13.95
11/28/00	4.5	0	4.0	0.75	9.25
11/29/00	0	4.5	4.5	1.0	10.0
11/30/00	1.5	3.0	4.5	0	9.0
12/11/00	3.0	4.5	1.5	0	9.0
12/12/00	1.5	4.5	3.0	0	9.0
12/18/00	3.0	3.25	3.0	0	9.25
12/19/00	4.5	3.0	1.5	0	9.0
12/27/00	4.5	1.5	3.0	0	9.0
12/28/00	4.5	3.0	1.5	0	9.0
1/3/01	5.0	3.0	1.5	0	9.5
1/4/01	4.5	3.0	1.5	0	9.0
1/9/01	3.0	4.75	1.5	0	9.25
1/10/01	3.25	2.0	4.25	0	9.5
Total	**71.75**	**59.95**	**51.45**	**5.0**	**188.15**

A total of almost 60 hours of observation spanning 19 days was conducted at Olsen's Beach. During this time period, seals were observed on only two days. Seals were observed foraging along the shoreline, chasing fish, and in one case eating a large salmonid that appeared to be a sockeye (Gearin et al. 2002). Surveys were conducted at the mouth of Umbrella Creek for a total of 51.45 hours on 19 days. Seals were observed on three of these days. In one case, a seal was observed chasing a large salmonid. A total of 5 hours of observation was conducted at the mouth of Big River during 5 days. No seals were seen at the mouth of Big River (Gearin et al. 2002).

In addition to work conducted by Gearin et al. (2002), additional observations of seals within the lake and on the spawning beaches were also made by MFM staff during spawning ground surveys and CART tracking during the 2000 spawning season. Between October 25, 2000 and February 13, 2001, a total of 17 days were spent on the lake. Seals were observed in the lake or along the spawning beaches on 8 of the 17 days. The first observation occurred on October 25, 2000 at Allen's Beach and the last observation occurred on January 31, 2001 between Olsen's Beach and Preachers Point. Observations from 2000/01 indicate that seals are present along the spawning beaches and lake throughout the sockeye spawning period. Examination of carcasses recovered from Allen's Beach indicated that most of the predation mortality was caused by river otters (Gearin et al. 2002). However, there is the potential that otters scavenged the remains left by seals, implicating the wrong animal. Sockeye during spawning are extremely vulnerable to predation by seals and the limited number of beach spawners in the lake could be drastically affected by only a handful of seals.

5.4.5.1.2 River Otters (Lutra canadensis)

River otters are common year-round inhabitants of Lake Ozette. As described earlier, there are no river otter population estimates for the Ozette watershed. River otter predation on sockeye salmon in the lake is poorly understood. As described above, river otters are known to prey upon adult sockeye salmon on the spawning grounds, but predation at other life history stages has not been documented. CART tagging studies conducted during RYs 2000 and 2001 indicate that there is potentially significant pre-spawning mortality occurring within the lake (Hughes et al. 2002). Holding mortalities resulting from predation may be associated with river otters. Gearin et al. (2002) recommend that further investigations of pre-spawning lake holding mortalities be conducted since the source of mortalities could not be determined in 2000 and 2001. Hughes et al. (2002) found that nearly 50% of the tagged sockeye could not be accounted for on the spawning grounds in 2001.

Predation of adult sockeye on the spawning grounds by river otters is cause for concern (Gearin et al. 2002). Preliminary field evidence collected from Allen's Beach during the RY 2000 spawning season indicates that nearly 34% of the sockeye were killed by river otters prior to the completion of spawning (total pre-spawning predation mortality was estimated to be 40% on Allen's Beach; 6% of these mortalities were attributed to harbor seals). It is possible that many of the mortalities linked with river otters are actually associated with harbor seals and that river otters are scavenging the remains left by seals. However, due to the fact that nearly all successful predation occurs at night along the spawning beaches, it was not possible to determine precisely which predators are responsible for the mortalities occurring.

5.4.5.1.3 Northern Pikeminnow (Ptychocheilus oregonensis)

A description of the Lake Ozette northern pikeminnow population is included in Section 2.2.8. As described above, northern pikeminnow are known to prey upon juvenile sockeye in the limnetic zone. However, only a small percentage (2-8%) of the northern pikeminnow population uses the limnetic zone throughout the year (Beauchamp et al. 1995). Beauchamp et al. (1995) determined that for every 1,000 large northern pikeminnows, 5,600 age-0 and age-1 *O. nerka* were consumed. Per capita consumption of juvenile *O. nerka* was 25 times less for northern pikeminnows than for cutthroat trout. However, 1,000 large (>300 mm FL) northern pikeminnow exclusively feeding on *O. nerka* in the limnetic zone could consume 620,000 fry annually (Beauchamp et al. 1995). Beauchamp et al. (1995) describe this as a worst case scenario, but they also found that all northern pikeminnow >450 mm FL within the limnetic zone exclusively fed on juvenile *O. nerka*. Beauchamp et al. (1995) concluded that predation could undermine recovery efforts if piscivore populations are sufficiently large, and that piscivore abundance must be determined in order to assess the total predation from piscivorous fish. Additional northern pikeminnow predation may be occurring within the lake near the outlet of the Ozette River, but no studies have been conducted to specifically target this area. Sockeye fry emigrating from Big River and Umbrella Creek have a brief increased susceptibility to predation from northern pikeminnow as they move through the nearshore environment during their migration to the lake's limnetic zone

5.4.5.1.4 Cutthroat Trout (Oncorhynchus clarki)

A description of the Lake Ozette cutthroat population is included in Section 2.1.6. Cutthroat trout are known to prey upon juvenile sockeye in Lake Ozette. Earlier work conducted by Dlugokenski et al (1981) found that sockeye composed no more than 4% of cutthroat trout's annual diet (sampling was mostly nearshore). As described above, Beauchamp et al. (1995) determined that 40% of the diet of large (>300mm FL), limnetic cutthroat trout consisted of age-0 and age-1 *O. nerka* during spring and summer months. Beauchamp et al. (1995) used a bioenergetics model to compute the annual consumption of age-0 *O.* nerka and determined that for each 1,000 cutthroat trout greater than 300 mm FL a total of 138,900 *O. nerka* fry were consumed. Beauchamp et al. (1995) estimated that the population of large (>300mm FL) cutthroat trout was between 5,000 to 10,000 fish at the time of their study and determined that this number of cutthroat trout would consume between 700,000 and 1,400,000 age-0 *O. nerka*. However, the estimated population of age-0 sockeye/kokanee at the time of their study was 1.5 to 3 times less than the estimated consumption; so caution should be used when considering these consumption estimates.

Cutthroat trout in Lake Ozette appear to be a significant predator of juvenile *O. nerka*. Much of the large discrepancy in diets described by Beauchamp and LaRiviere (1993) and Dlugokenski et al. (1981) are mostly likely a result of the different methods used to sample the lake. This degree of difference suggests that a much better understanding of the spatial and temporal distribution of large cutthroat trout in the nearshore and limnetic zones needs to be developed in order to more accurately understand and estimate predation rates. The high number of coho salmon using the lake for rearing and migration and their absence in the diet of cutthroat trout described by Beauchamp and LaRiviere (1993) is worth noting since the methods presented do not describe how salmonid species were differentiated. Dlugokenski et al. (1981) found juvenile coho in the stomachs of cutthroat trout almost half as often as sockeye were found. No sockeye eggs were documented in any of the cutthroat trout examined in either of these studies.

5.4.5.1.5 Sculpin (Cottus spp.)

Within Lake Ozette, sculpin predation is thought to be primarily on sockeye eggs during spawning and incubation. No estimate of the number of sculpin on the spawning beaches is available. The number or proportion of eggs preyed upon by sculpin on the spawning beaches is also lacking. Dlugokenski et al. (1981) examined the stomach contents of 74 sculpin and found eggs in 20. Sockeye eggs were only identified in 4 of the sculpins examined. It is unclear how many of the sculpins sampled were captured from the primary sockeye spawning grounds. In addition to egg predation on the beaches, sculpin also likely prey upon emergent fry, but this has not been documented in Ozette. No sockeye fry were found in any of the sculpin examined by Dlugokenski et al. (1981).

5.4.5.1.6 Other Native Fish Species

Other native fish species likely to prey on juvenile sockeye in Lake Ozette include juvenile coho salmon and steelhead trout. The lack of juvenile steelhead in vertical gillnet sampling conducted over a number of years suggests that steelhead rearing is limited to the tributaries. However, in 1999 over 8,200 age-0 steelhead were captured in what appeared to be a migration to the lake (from Umbrella Creek). Juvenile steelhead/rainbow trout primarily feed on aquatic insects, amphipods, aquatic worms, and fish eggs; they only occasional feed on small fish. Given the lack of spatial overlap in habitat used by juvenile sockeye and steelhead, it is assumed that steelhead predation on juvenile sockeye is very limited.

Juvenile coho salmon were also absent in vertical gillnet sampling reported in Beauchamp et al. (1995) and Dlugokenski et al. (1981). The lack of juvenile coho in vertical gillnet sampling could be a function of mesh and fish size. As described in Section 2.1.2.2.5 large numbers of age-0 coho have been observed migrating into the lake. Age-0 coho have also been captured and observed along the shoreline of the lake. Studies conducted in British Columbia and Alaska have shown that lake rearing juvenile coho can be significant predators of sockeye fry (Sandercock 1991; Ruggerone and Rogers 1992).

5.4.5.1.7 Non-Native Fish Species

Five non-native fish species have been documented in Lake Ozette: tui chub, American shad, yellow perch, largemouth bass, and brown bullhead (see Section 2.3). Tui chub, American shad, and brown bullhead were not considered to be likely predators of juvenile sockeye salmon. As described in Section 2.3.3, yellow perch were not found to consume juvenile sockeye in Lake Ozette. Only largemouth bass are considered likely predators of juvenile sockeye. Gillnet sampling conducted by Dlugokenski et al. (1981) and Beauchamp and LaRiviere (1993) yielded a total catch of only six largemouth bass. The only identifiable fish remains in the stomach contents were yellow perch. Beauchamp and LaRiviere (1993) concluded that largemouth bass and juvenile sockeye were spatially segregated during the growing season but a combination of conditions in spring could draw the bass nearshore earlier while fry and smolt pass through the littoral zone, making juvenile sockeye susceptible to predation by largemouth bass.

5.4.5.1.8 Avian Predators

No attempt to quantify avian predation rates for sockeye salmon in the lake has been conducted. Bald eagles have been observed to successfully prey upon adult sockeye on the spawning beaches. Other large raptors may also be capable of taking adult sockeye. However, bird predation on adult sockeye on the spawning beaches is thought to be rare. Predation by birds on juvenile sockeye has not been documented in the lake but likely occurs. Gearin et al. (2002) reported that osprey (*Pandion haliaetus)* were observed numerous times successfully preying upon kokanee in the vicinity of Allen's Beach. It is unclear whether these fish were kokanee or juvenile sockeye based upon the information provided in Gearin et al. (2002).

5.4.5.1.9 Terrestrial Mammals

Terrestrial mammals have not been documented preying on beach spawning sockeye in Lake Ozette. However, black bear tracks and scat were found by Gearin et al. (2002) along Allen's Beach during the RY 2000 spawning period.

5.4.5.2 Factors Affecting Predation

5.4.5.2.1 LWD Removal in Ozette River

Logjam removal in the Ozette River may have increased the efficiency and ability of harbor seals to migrate into the lake and therefore increased the number and frequency of seals using the lake during spring, fall, and winter.

5.4.5.2.2 Increases in Pinniped Population

See Sections 5.2.2.2.1 and 5.3.4.2.2 for complete discussions on regional pinniped population increases. In addition to regional increases in harbor seal abundance during the last 50 years, the utilization of Lake Ozette by harbor seals appears to be a recently developed strategy. Seals were not observed in the lake until the late 1980s (Larry Sears, personal communication, 2005; Adamire 2000). Seal predation in the lake is not thought to be a factor for the decline in Ozette sockeye abundance, but it is a factor that contributes to the population's inability to recover.

5.4.5.2.3 Abandonment of Ozette Village

See Section 5.2.2.2.2

5.4.5.2.4 Decreased Sockeye Abundance

See Section 5.2.2.2.3.

5.4.5.2.5 Changes in Lake and Fisheries Management

See Section 5.3.4.2.6

5.4.5.2.6 Introduced Species

Sockeye predation by introduced species appears to be very limited in Lake Ozette. There is very little spatial overlap between introduced piscivorous species and juvenile sockeye.

5.4.6 Disease

Lake Ozette sockeye are known to be susceptible to Infectious Hematopoietic Necrosis (IHN) virus, a fish pathogen common in most Pacific Northwest and Alaska *O. nerka* populations (Wood 1980). While this rhabdovirus has been responsible for high mortalities in juvenile sockeye from other Pacific Northwest and Alaska populations, it has not been implicated in adult salmonid pre-spawning mortalities. Disease is believed to have a low impact on adult sockeye holding in Lake Ozette. There is no direct evidence of significant disease mortality of free swimming adult sockeye in the lake. However, little is known about this life stage of Ozette sockeye, and it should be noted that in some years only a fraction of the adult fish enumerated at the weir are accounted for during lake and tributary spawning ground surveys. Radio telemetry studies conducted in 2001 were unable to detect movement after September in nearly half of the sockeye tagged, suggesting significant pre-spawning mortality. Disease has the potential to magnify the effects of predation and elevated water temperature because injured and stressed fish are more susceptible to disease. In addition, during some years when adult sockeye were trapped and their condition was recorded at the weir, a substantial number exhibited significant predator lacerations, which make holding sockeye prone to secondary infections by opportunistic infectious fish pathogens that are endemic to the watershed.

5.4.7 Tributary Hatchery Program

Hatchery practices implemented through the HGMP include measures to minimize potential disease and genetic impacts on beach spawning aggregations (see Section 3.2.3). The Umbrella Creek Hatchery "stock" poses limited genetic risk by breeding with beach spawning sockeye, since Umbrella Creek sockeye are essentially the same genetically as Olsen's Beach sockeye (NMFS 2003). Imprinting juvenile sockeye using on-station rearing in release watersheds reduces the risk of hatchery-origin sockeye straying onto beaches. Mark and recapture data collected at Olsen's and Allen's beaches indicates that few, if any, Umbrella Creek hatchery releases return to spawn on Lake Ozette beaches. For example, approximately 25% of the BY 1995 Umbrella Creek fed fry released were adipose fin clipped and in 1999, 121 adult sockeye salmon were sampled on Olsen's Beach and none were adipose fin clipped. This suggests that there was no or at least very little straying from tributary releases onto spawning beaches (MFM 2000). Carcass sampling from 2000 through 2002 at the primary sockeye spawning beaches was determined to be ineffective at monitoring the origin of sockeye based on fin clips since the condition of many carcasses precluded accurate determination of adipose fin clip status. Spawning adults returning from hatchery releases after 1999 were mass marked using thermal otolith marks, but the results from these returns are not yet available. In addition, hatchery operational protocols limiting the duration of the hatchery program limit the likelihood for Ryman-Laikre effects, should some straying to beaches occur.

5.5 LAKE OZETTE TRIBUTARIES

Lake Ozette sockeye utilize tributaries during three life history phases described in Section 3.1: adult sockeye entering, migrating, and holding (3.1.3); adult sockeye spawning and egg incubation (3.1.5); and sockeye fry emergence and dispersal (3.1.7). These life history phases in Lake Ozette tributaries are the focus of the limiting factors discussion presented in this section. Stream hydrology (4.4.1.6, 4.4.2.6, and 4.4.3.6), water quality (4.4.1.5, 4.4.2.5, and 4.4.3.5), floodplain conditions (4.4.1.1, 4.4.2.1, and 4.4.3.1), channel habitat conditions (4.4.1.3, 4.4.2.3, and 4.4.3.3), spawning gravel quality and quantity (4.4.1.4, 4.4.2.4, and 4.4.3.4), channel stability, predation, competition, and hatchery broodstock removal are all factors that have been evaluated to determine the degree to which each factor currently or in the past has limited sockeye salmon survival and productivity in Lake Ozette.

5.5.1 Watershed Hydrology

The hydrology of the Ozette Watershed has been poorly studied over the contemporary settlement period of the Ozette region. However, various lake level, climate, and hydrology data have been collected at various places in the watershed and coastal region, for different reasons, and these can be massed together to highlight the major physical patterns of the lake's hydrology. These data are presented in detail in Sections 4.2.5, 4.3.6, 4.4.1.6, 4.4.2.6, 4.4.3.6, 4.4.4.6, and 4.4.5.6. Within tributaries to Lake Ozette, the exact extent to which land use and channel modifications have affected and/or altered watershed hydrology cannot be determined with the limited data that have been collected. A summary of Lake Ozette tributary hydrology is included in Section 5.5.1.1 and a literature review of potential land use effects on stream hydrology is included in Section 5.5.1.2, with potential implications for Ozette hydrology summarized in Section 5.5.1.2.2.

5.5.1.1 Summary of Lake Ozette Tributary Hydrology

Due to the short record at the four stream gages on tributaries to Lake Ozette, only summary statistics for water year (WY) 2005 can be calculated. These data are displayed in Table 5.6. Data for Ozette River and Hoko River for WY 2005 and averages for the period of record are included as reference. The annual coefficient of variation (CV) is a measure of overall flow variability and was calculated using daily average discharge, with CV equaling the standard deviation of daily discharge divided by the annual mean daily discharge. For Ozette tributaries, these values (1.61 to 2.16) represent highly variable streamflow conditions. These CV values are similar to other perennial rain-dominated streams in the coastal Pacific Northwest, but with higher variability than other Western Washington streams with a considerable component of snow (Poff 1996). CV typically increases with a decreasing watershed area. Coefficient of variation values for Ozette River are similar to those defined by Poff (1996) as "super stable groundwater" streams with extremely stable daily flow regimes, largely due to the storage and stabilizing effect of Lake Ozette on the flow regime of Ozette River.

Table 5.6. Summary of streamflow statistics for Water Year 2005 (source: USGS and MFM unpublished streamflow data).

Stream Gage	Mean Discharge	Maximum Discharge	Max Date	Minimum Discharge	Min Date	Standard Deviation	Coefficient of Variation
Ozette River	453	1,377	1/23/2005	25.1	9/26/2005	327	0.72
Big River	92	2,258	11/24/2004	3.61	9/26/2005	162	1.61
Umbrella Creek	64	1,654	9/29/2005	2.53	8/27/2005	133	1.87
Crooked Creek	52	1,690	11/24/2004	0.66	9/10/2005	113	1.92
Coal Creek	23	731	11/24/2004	0.24	9/10/2005	58	2.16
Hoko River (WY '05)	324	8,570	11/24/2004	15.99	9/24/2005	536	1.65
Hoko River (Average)	402	8,678	na	21	na	589	1.47

For a comparison of peak flow values estimated during WY 2005, flood frequency and magnitude values were calculated using USGS Regional Regression Equations developed to estimate peak discharges for naturally flowing, unregulated streams in Washington State (Table 5.7; Sumioka et al. 1998). USGS Regional Regression Equations for the west side of the Olympic Peninsula were used to estimate peak flows for recurrence intervals from 2 to 100 years for the Ozette tributaries (Region 1 in Sumioka et al. 1998). Annual precipitation estimates were drawn from PRISM data (Table 5.7) and watershed area values were calculated for the basin area upstream of each stream gage location. Using these estimates, 2005 peak flow values in these Ozette tributaries had a return interval of between approximately 25 and 10 years, or 4% to 10% probability of occurring any one year.

Table 5.7. Estimated frequency and magnitude of peak stream discharges in Ozette tributaries.

Return Interval (Years)	Frequency	Big River	Umbrella Creek	Crooked Creek	Coal Creek
2	0.5	1,375	1,072	914	415
10	0.1	2,157	1,680	1,434	652
25	0.04	2,535	1,974	1,686	766
50	0.02	2,861	2,228	1,903	865
100	0.01	3,209	2,499	2,133	969

As stated in Section 4.2.5, Lake Ozette (7,554 acres) has an enormous impact on water storage and release up to the seasonal time step, creating a unique hydrologic signature for both Lake Ozette water levels and Ozette River discharge. Figure 5.36 displays a partial inflow-outflow hydrograph for Lake Ozette for WY 2004 and 2005. Instantaneous

(15-minute) discharge for Ozette River and Coal Creek were summed to estimate surface water outflow from the lake outlet region. Instantaneous (15-minute) discharge for Umbrella, Big River, and Crooked Creek were summed to get a partial picture of instantaneous inflow hydrology. Obviously, these data do not represent the total surface water inflow to the lake (50% of the watershed area) nor do they account for groundwater flow in or out of Lake Ozette, or evaporation from the lake itself. However, they do highlight the storage capacity of the lake, and time and magnitude delay of discharge in Ozette River.

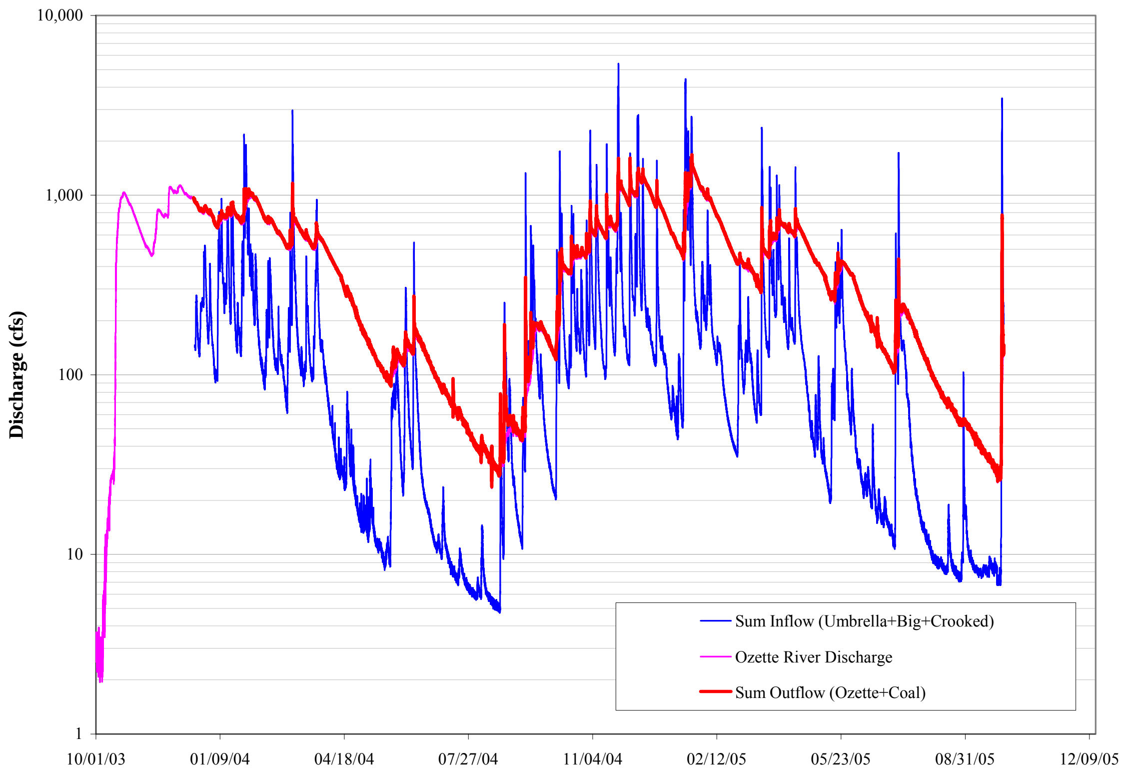

Figure 5.36. Summed partial inflow and outflow hydrographs for Lake Ozette.

5.5.1.2 Land Use Effects on Stream Hydrology

5.5.1.2.1 Literature Review

Land use can affect the hydrologic cycle by reducing infiltration capacity, changing the amount and effectiveness of vegetation cover (e.g. precipitation, interception and transpiration), changing the way water is routed to stream channels (shallow subsurface flow vs. overland flow), changing the timing and volume of runoff, and changing channel bed roughness and thus water velocity in channels and in overland flows. Alterations to these hydrologic controls can result in changes to base and peak flows. Such changes may be expected to result from a variety of land-use alterations, such as urbanization, grazing, agriculture, forest removal, road construction, and others. Increases in the magnitude and frequency of flow and flood pulse events can translate into alterations in channel morphology and pattern, and thus habitat for aquatic species. Changes in low base flow levels can alter critical dry season habitat for many aquatic species. Hundreds of studies worldwide have been conducted that relate altered water yields and flow regimes to changing land use, and generalizations can be drawn to the extent that land use in Ozette has altered hydrologic processes, but without quantification.

Obvious flow regime alterations occur following urbanization (e.g., Hollis 1975; Booth 1990; Booth and Jackson 1997) and conversion to agriculture (Wilk et al. 2001; Grip et al. 2005; Scott el al. 2005; Brown et al. 2005). Hydrologic impacts in forested regions have also been well studied, with over 166 controlled paired catchment studies worldwide (Andreassian 2004; Grip et al. 2005; Brown et al. 2005). In summary:

1. *Annual* water yield unequivocally increases for some time following a significant (10 to 25%) reduction of forest vegetation cover in a watershed (Bosch and Hewlett 1982; Bruijnzeel 1990; Stednick 1996; Sahin and Hall 1996; Bruijnzeel 1996; Robinson et al. 2003; Andreassian 2004; Jones and Post 2004; Brown et al. 2005).
2. Increases in water yield are largely a result of reduced precipitation interception and reduced transpiration (Bosch and Hewlett 1982; Brown et al. 2005).
3. The increase in water yield and flow is proportional to the percentage of the basin harvested or cleared (Bosch and Hewlett 1982; Stednick 1996; Grip et al. 2005; Brown et al. 2005).
4. Water yield changes are greater in high rainfall regions (Bosch and Hewlett 1982; Brown et al. 2005).
5. Changes in annual water yield or seasonal discharge following watershed disturbance are not necessarily static over time.
6. If the watershed is allowed to permanently revegetate to the native vegetation type with few road or other land use impact legacies, water yields will likely return to normal after a decade or decades (Stednick 1996; Jones and Grant 1996; Thomas and Megahan 1998; Jones and Post 2004; Hölscher et al. 2005; Brown et al. 2005).
7. However, if native forests are not allowed to recover through continued intensive or rotational land use activities, or if lasting legacies remain from significant permanent alterations (e.g., high road stream connectivity or permanent change to agriculture), then water yields will remain in a varying altered state (Thomas and Megahan 1998; Jones 2000; Grip et al. 2005; Brown et al. 2005).
8. Permanent changes to vegetation such as afforestation or permanent deforestation (agriculture or urbanization) have greater long-term water yield effects than disturbance and regrowth land use, but significant changes can occur nonetheless.

In watersheds where both forest harvest and significant road construction have occurred, few paired catchment studies (e.g., Jones, 2000) have been able to differentiate the hydrologic effects of roads over known impacts of forest removal. However, it is clear that the removal of the forested canopy and/or the associated presence of a road network alter hydrologic process quite differently, and can alter water production either synergistically or additively (Bowling and Lettenmaier 2001). Coe (2004) published a detailed review of the hydrologic (and sediment) impacts of forest roads with the following results:

1) Roads can dramatically alter runoff processes at the site scale through the production of hortonian overland flow (HOF) (Reid and Dunne 1984; Luce and Cundy 1994; Ziegler and Giambelluca 1997; Ziegler et al. 2000), the interception of subsurface storm flow (Megahan 1972; Wemple and Jones 2003), and stream piracy by ditches (Wemple et al. 2001).
2) Roads can intercept subsurface storm flow (LaMarche and Lettenmaier 2001; Bowling and Lettenmaier 2001; Wemple and Jones 2003) and more rapidly route water to the stream network (Wemple et al. 1996; Wemple and Jones 2003), augmenting the rising limb of stream runoff hydrographs (Wemple and Jones 2003) and reducing base flows (Bruijnzeel 1988).
3) Roads can lead to an extension of the channel network through gullying, or alteration of the channel network through stream piracy (Montgomery 1994; Wemple et al. 1996; Veldhuisen and Russell 1999; Croke and Mockler 2001).
4) Roads and road stream crossings can increase the landslide and gully frequency and thus delivery of coarse and fine sediment to the stream network (Sidle et al. 1985; Montgomery 1994; Veldhuisen and Russell 1999; Sidle and Wu 2001; Brardinoni et al. 2002).
5) Delivery of water and sediment to streams from road overland flow and ditch transport is highly variable in space, time and management intensity (Luce and Black 2001; Luce 2002), but largely dependent on cross drain spacing and road/stream connectivity at stream crossings or road induced gullies (Montgomery 1994; Wemple et al. 1996; Veldhuisen and Russell 1999; Croke and Mockler 2001; Wemple and Jones 2003; Croke et al. 2005).

In small watersheds in the Pacific Northwest with both forest harvest and road networks, *common* peak flow events (<1 to 2-year recurrence interval [RI] up to the 10-year RI) increase following forest harvest and road building in small catchments (Harr et al. 1975; Jones and Grant 1996; Thomas and Megahan 1998; Beschta et al. 2000; Jones 2000; Bowling et al. 2000; Jones and Grant 2001; Lewis et al. 2001; Jones and Post 2004). Changes in the magnitude of peak flows have been documented for events up to the 7- to 10-year RI (Lewis et al. 2001; Bowling and Lettenmaier 2001, respectively). However, the relative effect of forest harvest and roads on peak flows typically decreases as flow return interval increases beyond the 10-year RI (see below). Common peak flows (0.5- to 2-year RI [or greater]) have a major influence on channel form (Leopold 1964), as well as dominant and/or effective sediment transport (Wolman and Miller 1960; Knighton 1998; Lewis et al. 2001). Changes in the magnitude of these flows could induce profound changes to aquatic species' habitat quality and quantity. For example, if the frequency of common peak floods doubled, the geomorphic work performed on the channel would roughly double, destabilizing the channel.

Paired catchment data sets do not exist to support the hypothesis that low frequency *extreme* flow events (i.e., the 50- or 100-year recurrence interval) increase in magnitude following forest harvest or road building, and thus it is still a source of significant debate (Jones and Grant 1996; Thomas and Megahan 1998; Bowling et al. 2000). As time passes, longer term data sets in more controlled environments should shed light on these unknowns.

The cumulative effects of hydrologic alterations within large watersheds (i.e., the scale of the Ozette watershed or bigger) are relatively unknown and undocumented due to lack of long-term, controlled, paired-watershed studies at a large scale. However, numerous detailed physically based models (e.g., Distributed Hydrologic Vegetation Simulation Model [DHVSM]) have been developed to explain and control for physical processes at a large spatial scale and have proven useful in predicting changes in peak flows due to vegetation removal or forest roads. Several modeling studies (LaMarche and Lettenmaier 2001; Bowling and Lettenmaier 2001; Wigmosta and Perkins 2001; see Coe 2004) suggest that:

1) The largest changes are observed with the mean annual flood.
2) The effect of forest harvest and roads on peak flows decreases as flow return interval increases.
3) Road runoff effects are largely a result of the road interception subsurface storm flow.
4) Roads can concentrate or shorten the time to peak flow due to increased water routing efficiency.
5) Roads coupled with forest removal have an additive rather than synergistic effect.

As previously mentioned, *annual* water yield increases after forest vegetation removal, due to decreased (winter) precipitation interception and reduced (summer) transpiration. With time, forest regrowth, and no disturbance legacies (e.g., roads), these changes diminish toward background at the annual time scale.

Seasonal changes in water yield also change with time (Jones and Post 2004). With forest regrowth, winter peak flow changes are greatest during the first decade after removal. Similarly in winter rainfall-dominant regions, summer *base* flows increase for several years following forest vegetation removal, at small absolute levels but large proportional levels (Bosch and Hewlett 1982; Keppeler and Ziemer 1990; Hicks et al 1991a; Hicks et al 1991b; Jones and Post 2004; Brown et al. 2005). However, eventual regrowth of young vigorous trees results in significant increases in summer evapotranspiration when soil moisture and rainfall are at their lowest. Young regrowth trees transpire at much higher rates than to mature or old-growth forests (Andreassian 2004; Jones and Post 2004; Brown et al. 2005). Over extended periods following harvest and regrowth, summer streamflows can decline significantly below pre-harvest levels (Keppeler and Ziemer 1990; Hicks et al. 1991a; Jones and Post 2004), reducing quality of summer rearing habitat for salmonids (Hicks et al. 1991b). For long-term paired catchment studies, it has been found that relatively short rotations of young vigorous conifer stands (both native and non-native) significantly reduce summer dry season water yields and base flows at a high level proportional to undisturbed flows (Jones and Post 2004; Brown et al. 2005). In addition, for coastal watersheds where fog drip is a significant component of the summer water balance, forest canopy removal can reduce fog moisture capture and thus reduce summer water yield and base flows (Ingwersen 1985). However, local vegetation, climate, and topographic conditions will dictate the magnitude and timing of changes in seasonal water yield and base flow, with potentially offset timing impacts of different mechanisms (e.g., initial fog drip reduction followed by transpiration increase).

Generalized channel responses to changes in flow and sediment discharge are depicted in Table 5.8. Long- and short-term channel responses to flow and sediment discharge affect the quality and productivity of sockeye habitats. Relatively small changes in streamflow or sediment discharge can work cumulatively or additively with other channel and floodplain alterations, such as large woody debris removal, to decrease the inherent productivity of salmonid habitats (e.g., increased flow and decreased bed roughness results in increased bed mobility). Hydrological influences on salmonid behavior and productivity can be pronounced. General discussions of sockeye preferences and responses to flow conditions by life stage are discussed in Section 5.5.1.3.

Table 5.8. Generalized adjustment in stream geometry, pattern, and stability based on changes in flow and sediment discharge (Kellerhals and Church 1989; Knighton 1998; Downs and Gregory 2004), changes in base level (Downs and Gregory 2004), and changes in large woody debris.

Changes in Independent Factors	**Dependent or Adjustable Factors**							
	Channel Geometry			**Channel Pattern**		**Bed and Bank Stability**		
	Width[1]	**Depth**	**Slope**	**Sinuosity**	**Meander Wavelength**	**Degradation (Incision)**	**Aggradation**	**Bank Erosion**
Water discharge increases alone (e.g., deforestation)	↑	↑	↑	↓	↑	↑	↓	↑
Water discharge decreases alone (e.g., afforestation)	↓	↓	↓	↑	↓	↓	↑	↓
Sediment discharge increases alone (e.g., road building on unstable slopes)	↑	↓	↑	↓	↑	↓	↑	↑
Sediment discharge decreases alone (e.g., road & harvest BMPs)	↓	↑	↓	↑	↓	↑	↓	↓
Water and sediment discharge both increase (e.g., deforestation and road building)	↑	↕	↕	↓	↑	↕	↕	↑
Water and sediment discharge both decrease (e.g., downstream of a reservoir)	↓	↕	↕	↑	↓	↕	↕	↕
Water increases and sediment decreases (e.g., climate change toward a more humid pattern)	↕	↑	↓	↑	↕	↑	↓	↑
Water decreases and sediment increases (e.g., water supply diversion plus road building and harvest)	↕	↓	↑	↓	↕	↓	↑	↕
Base Level Increase (e.g., Higher Mean Lake Levels)	↕	↕	↓	↑	↓	↓	↑	↑
Base Level Decrease (e.g., Lower Mean Lake Levels)	↕	↕	↑	↓	↑	↑	↓	↑
Decreased large wood debris (e.g., riparian harvest)	↕	↕	↑	↓	↑	↑	↓	↕
Increased large wood debris (e.g., rehabilitation)	↕	↕	↓	↑	↓	↓	↑	↕

[1] Non-cohesive bank material (↑ = Increase; ↓ = Decrease; ↕ Either an increase or decrease)

5.5.1.2.2 Implications for Ozette Watershed Hydrology

Lack of long-term hydrologic data sets in the Ozette watershed preclude precise *quantification* of any potential changes to hydrology and flow regimes from land use and channel modifications. Speculation on the exact magnitude of changes would be unfounded. However, from the literature review above and knowledge of the processes known to affect flow regimes, *qualitative* changes can be described.

The Lake Ozette watershed has a temperate rainforest climate dominated by evergreen conifers with precipitation exceeding 100 inches (2500 mm) per year. The major watersheds draining into Lake Ozette have experienced one to two significant cycles of conifer vegetation clearing and regrowth over the last 100 years. At any given time, typically at least one third (>33%) of the watershed vegetation is in a hydrologically immature state (< 30 years old; Table 5.9). Vegetative hydrologic (im)maturity is defined as the capacity for a forest canopy to significantly intercept precipitation in the form of either rain or snow. Scientifically, this term does not apply only to rain-on-snow precipitation zones (see literature above). In the Lake Ozette watershed, current harvest rotations (~40 years) are pushing vegetation cover toward consistent immaturity (~75%). A moderately dense network of unpaved roads has been constructed over the last 60 years, with road densities greater than 6 mi/mi^2 on non-federal forested lands (Table 5.9).

Table 5.9. Sub-basin summary of road density, watershed disturbance, and hydrologic immaturity. (source: Ritchie, unpublished data; MFM, unpublished data)

Sub-Basin	**Basin Area** (mi^2)	**Road Density** (mi./mi^2 [year])	**Watershed Disturbance** (% of basin logged at least once by 2003)	**Hydrologic Immaturity** (% of basin vegetation less than 25 years old [circa 1979-2004])
Coal Creek	4.6	6.07 (2006)	98%	34.1%
Umbrella Creek	10.6	7.44 (2006)	99%	57.3%
Big River (All)	22.8	4.60 (1994) 6.43 (2006)	98%	34.1%
Big River (Upper)	8.43	6.50 (2006)	98%	45.4%
Crooked Creek	12.2	5.20 (1994)	90%	58.5%

NOAA's Matrix of Pathways and Indicators (NMFS 1996), provides qualitative ratings for watershed conditions such as road density and hydrologic condition. Watersheds with road densities less than 2 mi/mi^2 are considered *properly functioning*, while watersheds with road densities greater than 3 mi/mi^2 are considered *not properly functioning.* Road densities greater than 3 mi/mi^2 are considered *not properly functioning* because of significant (e.g., 20-25%) increases in drainage network density due to roads. NMFS (1996) does not provide thresholds for percent vegetative cover in hydrologic immaturity. However, the U.S. Forest Service (USDA 1993) combines road density and hydrologic immaturity to develop a watershed risk rating (Figure 5.37). This rating uses a threshold of 30% hydrologic immaturity to indicate potential watershed impairment. These indicators and thresholds are generic and “actual” impacts depend on watershed-specific conditions. However, these indicators do suggest the relative level of risk to resources from land use activities.

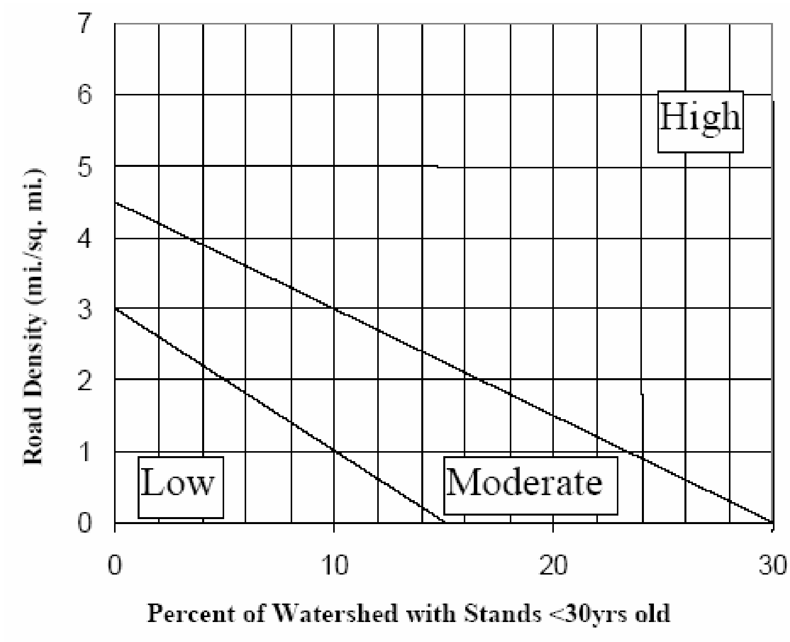

Figure 5.37. Watershed risk rating (source: USDA 1993).

If the above indicators are used as qualitative baseline for watershed hydrologic functionality, then every major sockeye sub-basin in Ozette would be rated as *not properly functioning* and at a high risk of resource impact (Table 5.9). If more conservative thresholds were used, such as 5 mi/mi^2 of road and > 50% hydrologic immaturity, then several Ozette sub-basins would still be rated as *not properly functional, at risk, or very likely impaired* (i.e., Umbrella Creek and Crooked Creek). These ratings will change when shorter harvest rotations alter the percentage of basin area in hydrologic immaturity.

From the literature cited above and local observation on the ground of altered vegetative patterns and drainage networks, a conservative assumption would be that land use has very likely impaired Ozette tributary hydrology, but the exact magnitude of change is unknown. From hundreds of controlled studies around the world and in the Pacific Northwest, every watershed that has experienced land use changes as significant as Ozette (>33% vegetative immaturity plus > 4 mi/mi^2 of road building) has experienced some changes in water yield and flow regime. In fact, out of all worldwide controlled studies, conifer forests in high precipitation zones such as Ozette experience the largest absolute and relative changes to flow regimes from timber harvest and regrowth (Bosch and Hewlett 1982; Brown et al. 2005

Since forest integrity and land use have been permanently changed in the Ozette watershed from old-growth conditions, water yield and flow regimes would not be expected to be able to fully recover to their original state. In Pacific Coast conifer watersheds similar to Ozette, common peak flow events (<1 to 2-year recurrence interval up to the 10-year RI) increase following forest harvest and road building. However, the relative change and thus significance of this potential increase is unknown in Ozette (e.g., 5%, or 50% increase in the magnitude of a 2-year event). Large peak flood events (i.e., the 50- or 100-year recurrence interval) would not be expected to be influenced by land use change in Ozette.

Initially upon conversion from old-growth conifer to commercial plantation conifer in the Ozette watershed, base flow (summer) water yields would be expected to increase for several years. Exceptions might occur for streams located within the coastal fog belt, where canopy removal could reduce summer base flow contributions from fog drip (e.g., Coal and Umbrella Creek). However, over the long term with permanent conversion to plantation conifer, base flow (summer) water yields would be expected to decline below pre-harvest conditions due to the vigorous dry season (summer) growth of young plantation conifer trees (<40 years old) and reduced winter water storage from timber harvest and roads. However, again the relative change and thus potential significance of long-term decreased base flows is unknown in Ozette (e.g., 5% or 50% decrease in summer 7-day low flow). For additional factors potentially affecting base flow, see Section 5.5.1.4.

Obviously, quantitative hydrology remains a data gap in Ozette. Due to the ubiquitous nature of land use change in Ozette, no controlled basins are currently available locally to test the scientific principles outlined above. However, future research could take advantage of modern watershed hydrology modeling to help quantify a range of likely scenarios of how land use has affected water yields and flow regimes in Ozette. For example, a distributed watershed model (Distributed Hydrology Soil Vegetation Model [DHSVM] or similar) could be developed to simulate historical, current, and future lake inflow hydrology as a result of changes in land use, vegetation cover, drainage density, roads, and soil water storage. This model could be coupled with the unsteady HECRAS hydraulic model of the Ozette River (Herrera 2005) to develop a fully encompassing watershed hydraulic and hydrological model of Ozette that incorporates lake inflow, outflow, and evaporation (i.e., a water budget). From a development like this, the range of potential impacts on sockeye salmon survival in both tributaries and the lake could be more deeply understood.

5.5.1.3 Tributary Streamflow and Sockeye Survival

Beyond the physical influences streamflows have on stream channels (see Sections 5.5.1.2 and 5.5.4.3), high flows (natural or anthropogenically modified) can also significantly alter the behavior of salmonids and their ability to access certain habitats. One of the principal controls of available spawning habitat in gravel bedded rivers is streamflow. Streamflow regulates the quantity of gravel area covered by water and the velocity and depth of spawning gravel. Each salmonid species has a range of preferred spawning conditions, which include substrate size, water velocity, and depth (Bjornn and Reiser 1991).

Bortleson and Dion (1979) evaluated Ozette tributary spawning habitat availability based on preferred velocities of 1 to 2.5 ft/sec and depth greater than 0.5 ft to determine the range of preferred flows. Bortleson and Dion (1981) report the preferred stream discharge in Big River and Umbrella Creek as 154±74 and 85±41 cfs respectively. Figure 5.38 depicts Umbrella Creek average daily streamflow (cfs) and the preferred streamflow conditions during spawning based on analysis conducted by Bortleson and Dion (1979). Prolonged dry periods in early fall resulting in low streamflows can delay the migration of adult sockeye into Ozette tributaries. Low flows in 2002 resulted in the delay of sockeye entering Umbrella Creek; the first sockeye did not migrate upstream of RM 0.8 until November 13, 2002. Delayed migration may make adult sockeye more prone to predation in lower Umbrella Creek or in holding areas off the confluence in the lake, as well as affect fitness and overall spawning success.

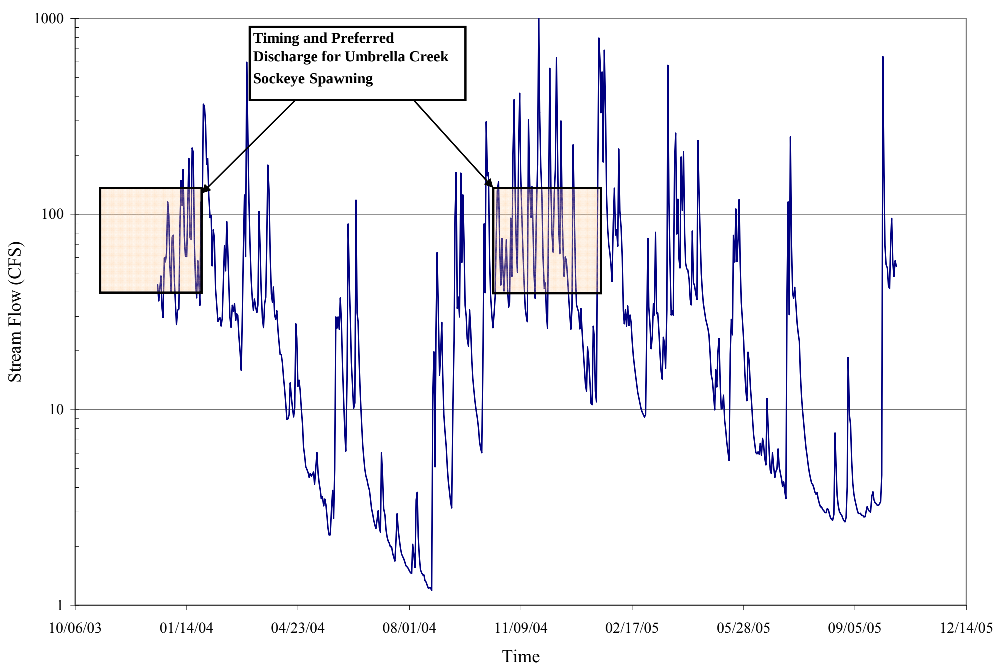

Figure 5.38. Umbrella Creek average daily stream discharge and sockeye spawn timing and preferred flow conditions (modified from Bortleson and Dion 1979)

Extended periods of high streamflow (caused by high storm frequency and intensity) can shift the distribution of spawning from “normal” positions in the channel to the margins where velocity and depth more closely match the preferred conditions (e.g., Ames and Beecher 2001). When this occurs and is followed by normal or low flows, eggs in redds constructed along the channel margins or in less optimal positions in the channel may experience increased mortality during incubation due to redd dewatering, or fine sediment intrusion. Extended dry periods yielding low flows following more or less “normal” flow conditions can produce the same effect with respect to redd dewatering. Conversely, below average flows during spawning that force fish to spawn low in the channel (thalweg), followed by large flood events, can increase the susceptibility to redd scour (Ames and Beecher 2001; Lapointe et al. 2000; see Section 5.5.4.3). Thus, for sockeye spawning in compound channels under variable discharge regimes, there is a trade off between spawning low in the cross-section and risking scour mortality versus spawning high along channel margins and risking redd desiccation or sedimentation related mortality. Figure 5.39 illustrates dewatered redds in Big River during week 9 of the 2005/2006 spawning season, after a period of minimal rainfall and low streamflow. Figure 5.40 shows the Big River discharge hydrograph for the 16-week sockeye spawning season during 2005/2006. Figure 5.41 displays the same discharge data, but as discharge exceedence curves for grouped two-week periods covering the same spawning season. Sockeye salmon spawned throughout the period shown, but peak spawning occurred in November (weeks 5 to 10) during moderate discharges. Following this peak spawning period, discharge dropped precipitously due to an abnormally long period without significant rainfall (weeks 11 and 12). Weeks 11 and 12 had median (50 percentile) discharges an order of magnitude less than during earlier or later periods.

Dozens of redds created during weeks 5 to 10 became completely dewatered to depth and exposed to low ambient-air relative humidity for a two-week period (weeks 11 and 12), especially in compound channel cross-sections with a distinct thalweg and lateral bar deposits. Furthermore, redds created high along channel margins also experienced significant fine sediment deposition following January flood events (weeks 15 and 16) with turbidity values over 500 NTU and suspended sediment concentrations over 1000 mg/L. Conversely, fish that spawned very low in the channel during weeks 11 and 12 were at the greatest risk of bed disturbance during early January (weeks 15 and 16). Fish that spawned in middle elevation points in the cross-section (weeks 8, 9, 10) and survived dewatering due to hyporheic flow maintenance, were in the best location to avoid subsequent high discharge disturbances. This example illustrates the tradeoffs between spawning low in a cross-section and avoiding dewatering, compared to spawning higher in the cross-section and avoiding bedload transport and scour. In summary, high streamflow variability during the sockeye spawning and incubation period can result in reduced probabilities of successful egg to fry survival. In relatively flashy rain-dominated watersheds on the Olympic Peninsula, flow variability is a survival factor that salmonids have naturally had to contend with. However, human land use practices (e.g., forestry and agriculture) can alter flow regimes and increase the variability of flows during the incubation period (see Section 5.5.1.2), by reducing water retention and base flows and increasing common (<2-year RI) peak flows.

Figure 5.39. Example of dewatered and partially dewatered sockeye salmon redds in Big River during week 9 (source: MFM photo archives).

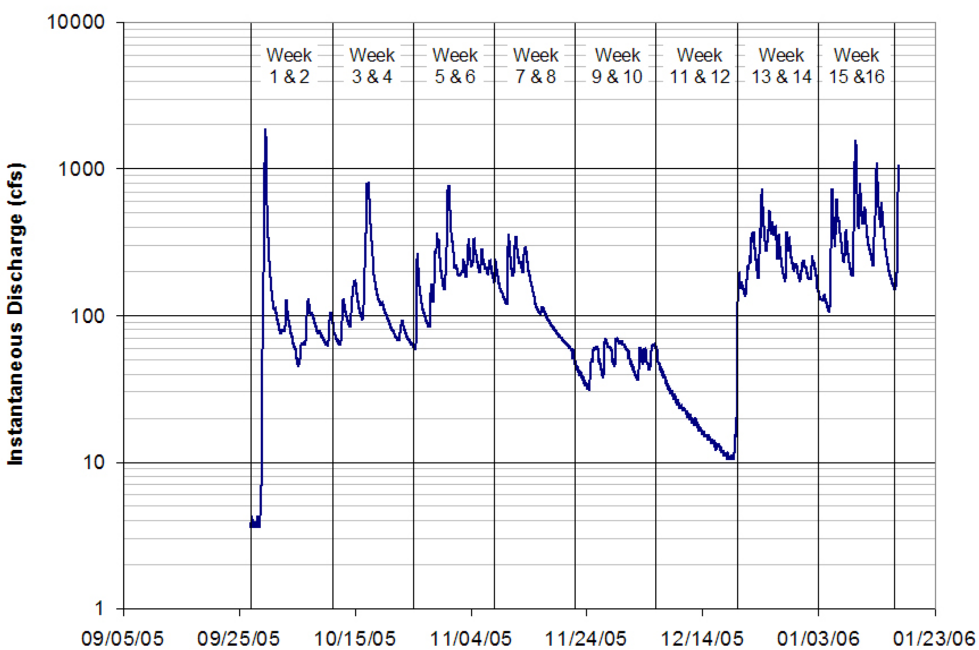

Figure 5.40. Big River hydrograph during water year 2006 sockeye spawning period (source: MFM provisional streamflow data).

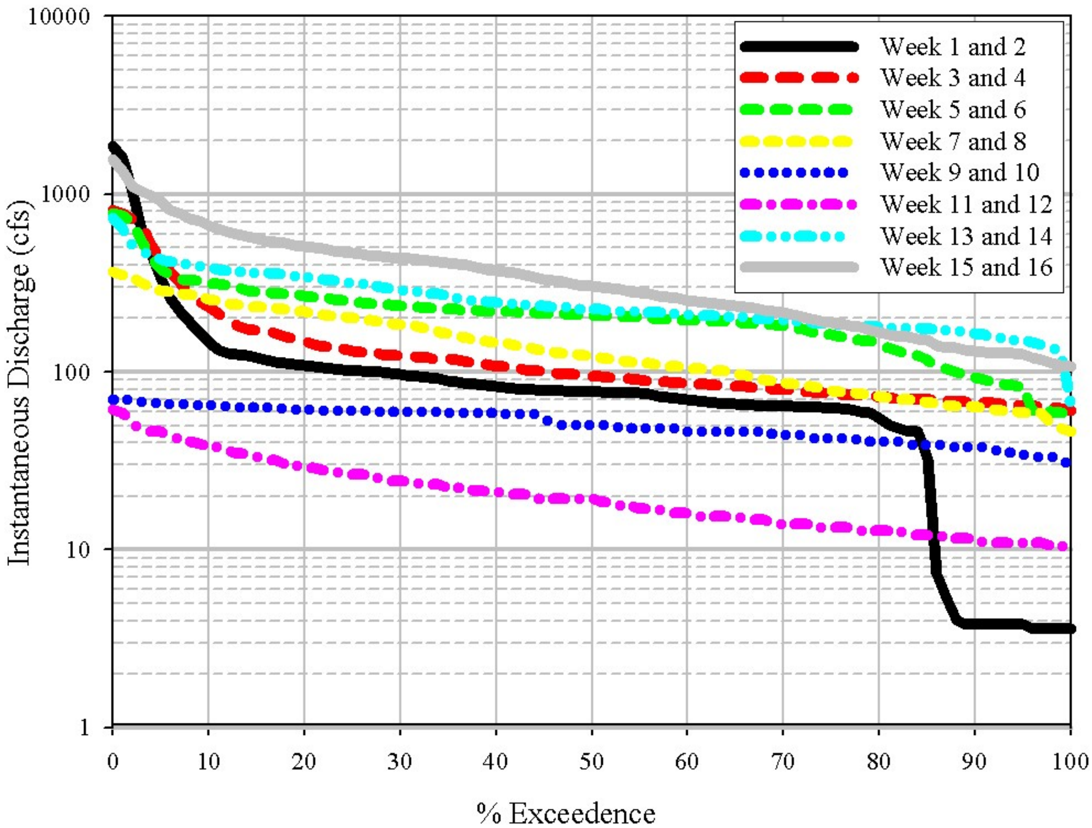

Figure 5.41. Big River flow duration curves over the 16-week spawning period for sockeye salmon, water year 2006. Weeks 1 and 2 (27-Sep to 10-Oct); Weeks 3 and 4 (11 Oct to 24 Oct); Weeks 5 and 6 (25 Oct to 7 Nov), Weeks 7 and 8 (8 Nov to 21 Nov); Weeks 9 and 10 (22 Nov to 5 Dec); Weeks 11 and 12 (6 Dec to 19 Dec); Weeks 13 and 14 (20 Dec to 2 Jan); Weeks 15 and 16 (3 Jan to 16 Jan). Source data based on MFM provisional streamflow data.

High or higher than average flows during spring may be beneficial to the offspring of tributary spawners. It is assumed that higher flows and increased stream velocities increase the rate of emigration into the lake, decreasing exposure to predation. Tabor et al. (1998) suggested that predation rates were low in most sites studied in the Cedar River during the 1997 fry emigration to Lake Washington because of high streamflow. They found that at mid-channel sites, where velocities were moderate or high, little predation of sockeye salmon was observed. They found the highest levels of predation in side-channels and outlet channels to off-channel habitats where velocities were lowest. However, no local data exist in the Ozette watershed to quantitatively define the exact magnitude of hydrologic changes or variability due to land use. Thus any increased impact to sockeye survival is an unknown and remains a data gap.

5.5.1.4 Potential Effects of LWD Removal and Channel Alterations on Streamflow

Channel-floodplain connectivity along Big River and other tributaries (Umbrella, Crooked, etc) has been altered as a result of wood roughness removal (Kramer 1953), channelization caused by roads, and channel incision (Herrera 2006). Beyond the habitat impacts of these geomorphic changes, significant hydrological impacts have likely occurred. Floodplains are significant storage zones of water from multiple sources, including overbank river and tributary water, groundwater, hillslope runoff, and direct precipitation (Mertes 1997; 2000). Floodplain water storage, both on the surface and in subsurface pore spaces, can significantly reduce peak discharges (Whiting and Pomeranets 1997; Mertes 2000) and can significantly increase baseflow recharge during dry periods (Kondolf et al. 1987; Whiting and Pomeranets 1997; Whiting 2002; Fleckenstein et al. 2004). Altering the inundation frequency and magnitude of floodplains (e.g., through channelization or roughness reductions) can alter the effectiveness of floodplains at storing water both on the surface and subsurface (Mertes 2000). Channel incision can lower the ambient water table and more effectively drain floodplains and associated wetlands, as can significant groundwater pumping (Kondolf et al. 1987; Fleckenstein et al. 2004).

Golder (2005) investigated the potential storage capacity of the Big River floodplain along 5 miles of Big River. Assuming a floodplain area of 2.5 square miles (5 miles long by ½ mile wide), a subsurface aquifer porosity of 20%, and a workable unsaturated zone thickness of 5 feet, over 69 million cubic feet of water could be stored in the current unsaturated zone of Big River. If this storage volume was full at the beginning of summer and released over a 90-day period (say June 15 to Sept 15) at a constant rate, base flows would be theoretically augmented by 9 cubic feet per second (cfs). In reality, this augmentation rate would change over time, with larger (than 9 cfs) inputs earlier in the 90-day period and smaller inputs (less than 9 cfs) during the end of the period (Golder 2005). While these estimates provide a maximum benefit of floodplain storage, they do indicate the importance of these areas for streamflow maintenance.

5.5.2 Water Quality

A complete review of water quality data for Ozette sockeye tributaries is included in Sections 4.4.1.5, 4.4.2.5, and 4.4.3.5. Meyer and Brenkman (2001) point out that DO, pH, and stream temperature failed to meet state water quality standards in some of the Ozette tributaries during their sampling period and voiced additional concern over high turbidity levels in Umbrella Creek and Big River. Jacobs et al. (1996) concluded that no obvious problems for sockeye salmon appear evident based on pH, DO, and conductivity. Jacobs et al. (1996) suggests that water temperatures in Ozette tributaries do not directly jeopardize sockeye salmon survival because the periods of high stream temperature and sockeye presence do not coincide. A comparison of recent (1990-2005) temperature data from Umbrella Creek, Big River and Crooked Creek indicate there is very little over lap between natural-origin sockeye and stream temperatures greater than 16°C (Figure 5.42).

The only water quality attributes measured during the period that sockeye utilize tributaries that may act directly to limit sockeye salmon survival and productivity are pH and turbidity. Meyer and Brenkman (2001) suggested that the low pH levels observed in Coal Creek and Crooked Creek are below values at which salmonid egg development and hatching success can be affected. In laboratory trials, Ikuta et al. (1999) found that at pH 5.8 kokanee homing behavior was completely inhibited and at pH 6.0 spawning behavior was inhibited. Recent water quality data sampling work conducted by MFM showed very similar results to those found by Meyer and Brenkman for temperature, pH, turbidity, and DO. No specific investigation of pH levels and salmonid productivity have been conducted in Ozette tributaries. Most of the low pH levels recorded by Meyer and Brenkman (2001) were during high flow events in Coal and Crooked Creeks. MFM pH data collected during the sockeye spawning period in Umbrella Creek and Big River averaged 6.5 and 6.6 respectively.

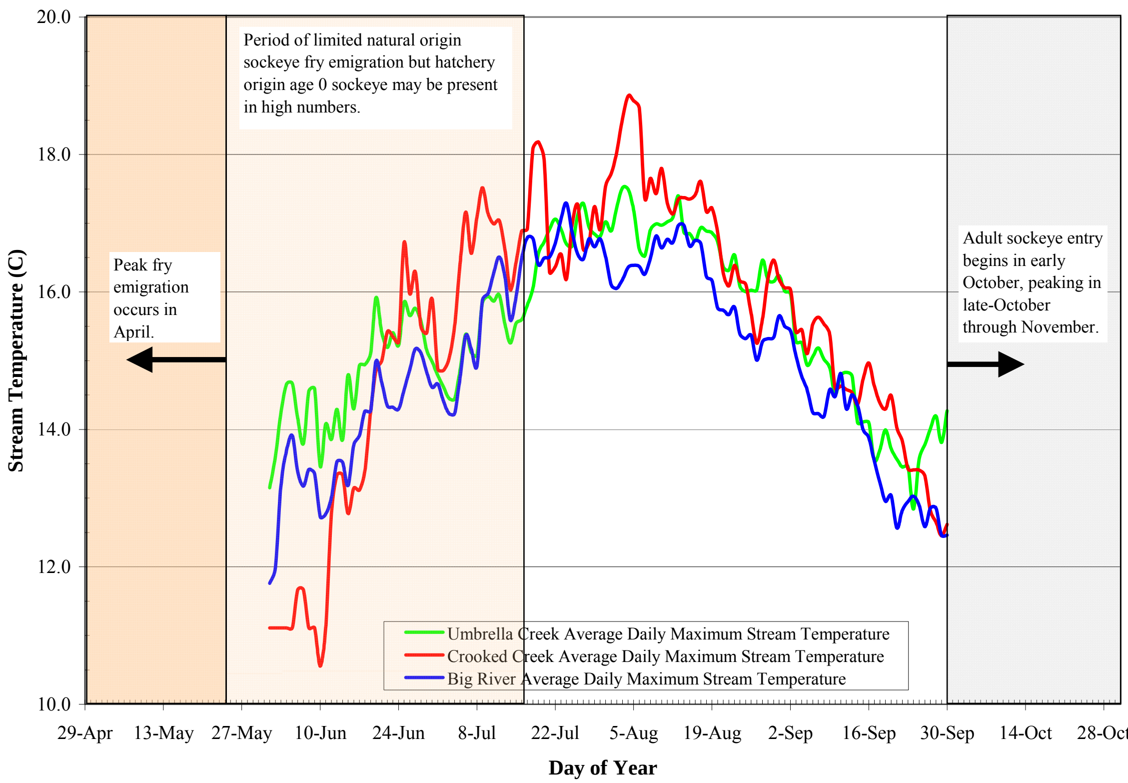

Figure 5.42. Period of sockeye salmon fry and adult utilization in Lake Ozette tributaries contrasted with annual average daily maximum stream temperature in lower Umbrella Creek (n=9), Big River (RM 1.7-4.8; n=4), and lower Crooked Creek (n=4).

High levels of turbidity in Umbrella Creek and Big River have been documented and/or described by Meyer and Brenkman (2001), Jacobs et al. (1996), Smith (2000), and MFM (2000). While turbidity data are quite limited for Ozette tributaries, it was still possible to compare turbidity levels in multiple stream systems for several storm events. Figure 5.43 depicts recorded peak turbidity (NTUs) for Big River and Coal, Umbrella, Crooked, and Siwash Creeks during 21 small to medium scale storm events. Coal Creek, Big River, and Umbrella Creek all show higher turbidity levels during all storm events where data exist, similar to results found by Meyer and Brenkman (2001). In the Ozette watershed, tributary turbidity and SSC are well correlated, indicating that turbidity is a decent surrogate for SSC (Figure 4.82; see also Section 4.4.4.5.1).

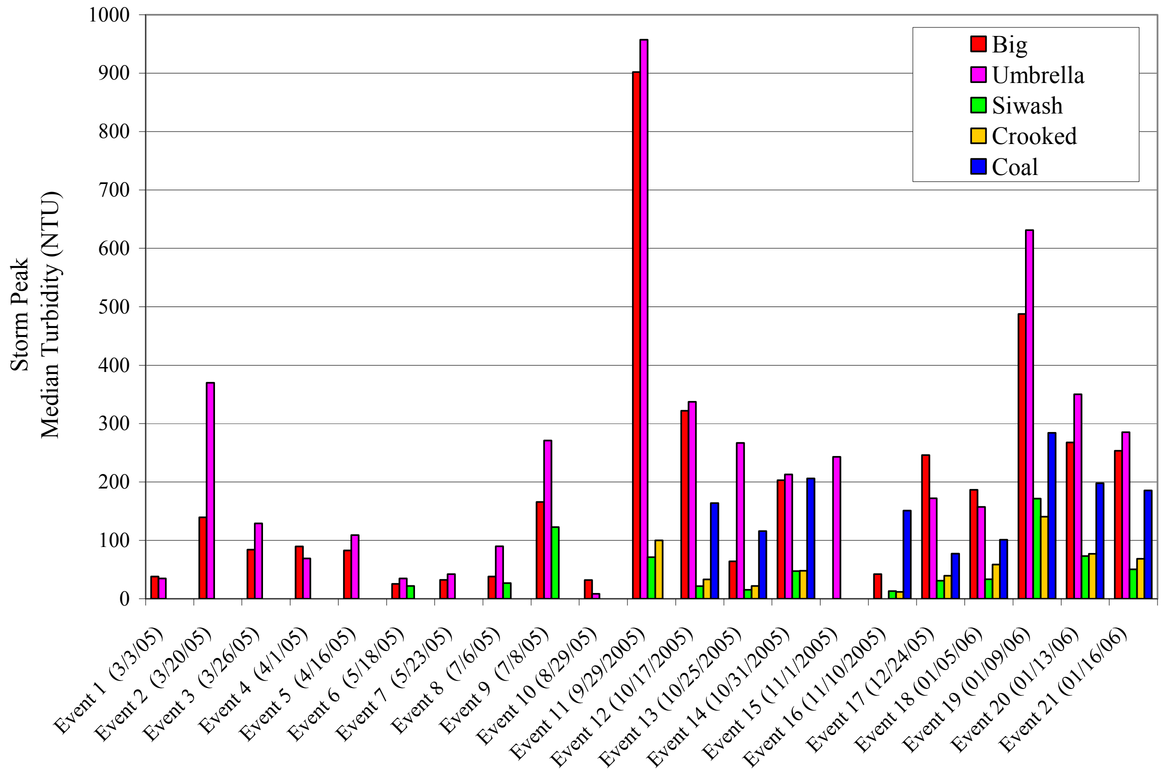

Figure 5.43. Peak turbidity (NTUs) for Big River and Coal, Umbrella, Crooked, and Siwash Creeks during 21 small to large scale storm events (source: MFM, unpublished turbidity data).

Elevated turbidity levels can directly affect fish survival through altered behavioral changes, such as reduced visual sight distance, prey feeding, and predator avoidance. However, the suspended particulate material in the water, for which turbidity is a surrogate, is the main direct and indirect factor impacting fish and biota. Thus, both SSC and turbidity have been studied in detail in relation to fish survival, habitat integrity, and stream health.

Elevated turbidity and SSC have numerous negative impacts on fish and other stream biota, including behavioral effects, physiological effects, and habitat effects. Behavior effects of turbidity and SSC on fish include changes in foraging, predation, avoidance, territoriality, homing and migration (Waters 1995; Bash et al. 2001). Physiological effects include gill trauma and damage, reduced respiration, changes in blood physiology due to stress, disruption of osmoregulation during salmonid smolt migration, and reduced oxygen transfer to incubating eggs in gravel affected by sedimentation (Waters 1995; Bash et al. 2001). Habitat impacts include changes in the abundance and diversity of prey (e.g., invertebrates and mircofauna); altered primary production (i.e., photosynthesis: Waters 1995; Bash et al. 2001; Suttle et al. 2004); changes in temperature regimes (Waters 1995); increased channel sedimentation (Everest et al. 1987); increased gravel and cobble embeddedness (Bash et al. 2001); reduced gravel permeability, intergravel water flow and oxygen transfer (i.e., hyporheic flow); reduced gravel porosity and emergence success (McNeil and Ahnell 1964; Everest et al. 1987; McHenry et al. 1994; Reiser 1998); reduced pool habitat volume and habitat complexity (Lisle and Hilton 1999); and increased bedload mobility and scour depths (Lisle et al. 2000).

Using detailed SSC data in correlation with continuous turbidity data from Coal Creek, the potential effects of suspended sediment on adult and juvenile sockeye salmon physiology and behavior were assessed in comparison to empirical severity models in the literature (Newcombe and Jensen 1996). These data are presented in Section 5.3.3.2. Due to the significantly higher turbidity values in tributaries, such as Big River and Umbrella Creek (Figure 5.43), it is likely that turbidity and SSC have greater impact on sockeye physiology and behavior (adults and juveniles) in other tributaries than estimated for Coal Creek near the confluence of Ozette River. Furthermore, the frequency of turbidity events is significantly higher during the period that sockeye inhabit Ozette tributaries versus the Ozette River. Figure 5.44 depicts the total number of hours that turbidity exceeded any given NTU value. Future turbidity and suspended sediment data collection in Umbrella Creek and Big River will be needed to fully evaluate the potential effects of turbidity and SSC in tributaries.

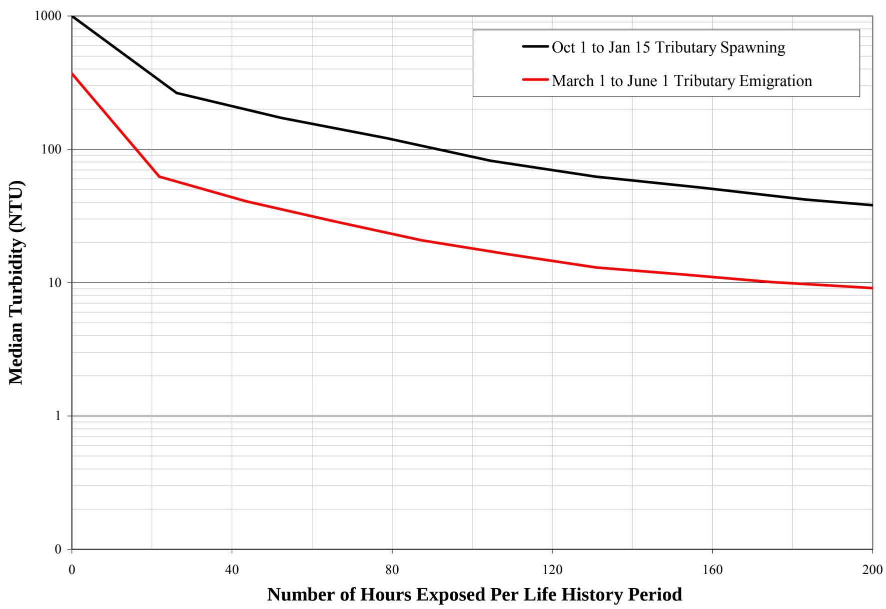

Figure 5.44. Duration of time (hours) that turbidity exceeded a given NTU during the spawning or emigration period (Umbrella Creek, WY 2006; source: MFM, unpublished data).

5.5.3 Floodplain Conditions

Descriptions of floodplain conditions in Big River, Umbrella Creek, and Crooked Creek are included in Sections 4.4.2.1, 4.4.1.1, and 4.4.3.1. Although no formal floodplain assessment has been conducted in the watershed, general observations of floodplain conditions seem to indicate better conditions exist in Umbrella and Crooked Creeks than in Big River. Herrera (2006) notes that widespread channel degradation was observed during their field surveys and that all tributaries showed some degree of channel incision, decreased channel-floodplain connectivity, high sediment loading, limited LWD loading, and diminished future LWD recruitment potential. Herrera (2006) determined that the majority of sediment production and greatest channel incision and channel instability were in Big River.

It is difficult to directly link floodplain conditions to limitations on sockeye salmon productivity. However, channel-floodplain connectivity plays an important role in sediment transport and storage dynamics, as well as in regulating hydraulic and hydrologic processes. Floodplains are significant storage zones of water from multiple sources, including overbank river and tributary water, groundwater, hillslope runoff, and direct precipitation (Mertes 1997; 2000). As channels incise and become disconnected from their floodplains, several responses can be expected, including lowering of water table, decreased bank stability, increased sediment transport, increased stream energy, increased water depths at flood stage, and general channel instability. Cumulatively, altered floodplain processes coupled with other changes in watershed processes, such as increased sediment and water production and delivery to the channel network, can result in increased fine sediment levels, decreased bed stability, and increased sediment delivery to the lake. Herrera (2006) suggest that channel incision and floodplain disconnection indicate that fine sediment transport of instream sediment has increased relative to historical levels and has the potential to degrade lakeshore habitats.

Other floodplain alterations such as stream adjacent roads, bank armoring, and wood removal can have localized direct effects on habitat suitability and stability. Herrera (2006) suggests that LWD loading appears to influence the magnitude of channel incision and channel-floodplain connectivity in Ozette tributaries. Herrera (2006) found that most areas with poor channel-floodplain connectivity were most often associated with poor wood loading conditions and that where good wood loading conditions were present, fair to good channel-floodplain connectivity still existed. Maintenance or reestablishment of channel-floodplain connectivity in Ozette tributaries is critical to recovery of pre-disturbance channel processes and habitat regulating mechanisms. Some areas where channels have become disconnected from their floodplains may recover naturally over time, as forests grow, LWD is recruited to the channel network, and channels evolve toward a more stable width, depth and slope configuration (Herrera 2006). However, many areas either have no adjacent riparian forests due to conversion to pasture, residences, and/or roads, or have poor wood recruitment potential. Section 4.4.2.1 and Figure 4.55 illustrate the type and location of floodplain alterations in Big River. Without some form of intervention, channel and habitat conditions adjacent to these impacted floodplains are expected to continue to degrade and result in lower quality sockeye salmon habitat in the future.

5.5.4 Channel Habitat Conditions

5.5.4.1 Instream LWD and Pool Habitat Conditions

A comprehensive inventory of habitat conditions in tributaries to Lake Ozette and the Ozette River can be found in Haggerty and Ritchie (2004). Instream LWD conditions are described in detail for Umbrella Creek (Section 4.4.1.3), Big River (Section 4.4.2.3), Crooked Creek (Section 4.4.3.3), Coal Creek (Section 4.4.4.3), and Siwash Creek (Section 4.4.5.3). Haggerty and Ritchie (2004) evaluated LWD data at the segment level for the Ozette tributaries based upon LWD frequency (pieces/100m and pieces/BFW), key and large (>50cm diameter) piece frequency, and the percent of pieces of LWD classified as large (Figure 5.45). They found pieces per 100 m rated good in only 25% of the habitat segments surveyed and that 44% and 32% of the segments rated fair and poor, respectively. Key pieces/BFW rated good in only 1% of the segments and fair in 19%; just over 80% of the segments rated poor (Haggerty and Ritchie 2004). LWD > 50cm diameter/100 m rated good in 23% of the segments and fair in 39%; the remaining 38% of segments rated poor. Haggerty and Ritchie (2004) point out an interesting relationship in the Big River mainstem where high frequency, large diameter pieces of LWD occur in three discrete forested reaches between agricultural land, where LWD abundance is much lower. The highest LWD piece count/100 m was found in Coal Creek and lowest was found in Big River.

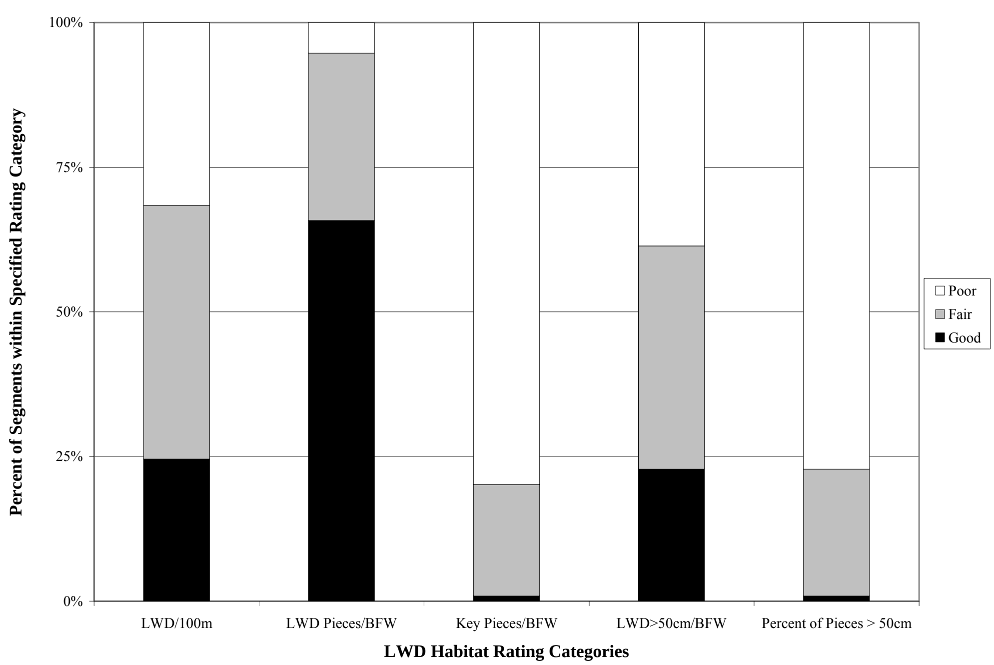

Figure 5.45. Ozette watershed tributary segment level LWD habitat ratings (source data from Haggerty and Ritchie 2004).

5.5.4.1.1 LWD and Instream Habitat Complexity

The influence and importance of LWD on channel dynamics and stability, as well as fish habitat quality, is one of the most studied aspects of forest and stream interaction (Maser and Sedell 1994; Gregory et al. 2003; Montgomery and Piegay 2003). The ability of LWD to enhance fish habitat is well documented (Grette 1985; Bisson et al. 1987; Cederholm et al. 1997). Large woody debris has been shown to affect pool formation (Bilby and Ward 1989; Bilby and Ward 1991; Beechie and Sibley 1997), pool size, depth and habitat quality (Haggerty and Ritchie 2004), bed stability (Bilby 1984; Smith et al. 1993), sediment accumulation and bar formation (Lisle 1986; Bilby and Ward 1989), sediment size (texture) (Buffington and Montgomery 1999b), as well as to sort and accumulate fine sediment and organic debris (Bilby and Ward 1989). All of these factors are thought to significantly influence the physical quality and complexity of fish habitat. Large woody debris can also act to provide cover and create channel complexity, which is critically important to some salmonid species such as coho (Nickelson et al. 1992).

Large woody debris can have profound hydraulic and hydrological effects on channels and floodplains (see Sections 5.5.1.4 and 5.5.4.1.2). Logjams and LWD can also act to store and stabilize sediment within the channel (see Section 5.5.4.2.2 and 5.5.4.1.3). The ability of LWD to form pools and instream habitat complexity is also important. The role of LWD in stabilizing channels, storing spawning gravels, and maintaining floodplain connectivity is thought to be critical to successful sockeye spawning in Big River. Also important to sockeye salmon are the high quality pool habitats formed and maintained by LWD. Haggerty and Ritchie (2004) summarized pool attributes from 1,963 pools surveyed in Ozette tributaries and found that average maximum pool depth was strongly correlated with pool forming LWD size class, as was the percent by length of pools classified as having moderate to good woody cover (Figure 5.46). Pools formed by LWD >50cm diameter and greater than 16 feet in length were found to be 53% deeper than pools formed by LWD <50 cm in diameter and free- or bed-formed pools. Key and large+ piece-formed pools are 53% deeper than medium, small, and free-formed pools. The relationship between piece size and pool depth and cover illustrates the important influence of large LWD (> 50cm diameter) on pool quality.

Haggerty and Ritchie (2004) found that the quantity of pool habitat is also strongly influenced by LWD piece size (Figure 5.47). For example, even though key-sized LWD comprised only 593 of 30,289 inventoried pieces of LWD (2%), it formed 17% of the inventoried pool habitat by length and LWD pieces > 50 cm in diameter formed 76% of the LWD-formed pool habitat, even though these combined size classes represent only 18% (5,520 pieces) of the inventoried LWD. Small and medium-sized LWD make up 82% of the inventoried LWD (24,769 pieces), but form only 24% of the LWD-formed pool habitat. The importance of pool habitat for sockeye salmon is thought to primarily be limited to pre-spawning holding. The frequency of holding pools was evaluated throughout the tributary spawning range of Ozette sockeye and does not appear to be a significant limiting factor. The frequency of holding pools in general is thought to have declined, but sufficient numbers of holding pools exist in stream areas utilized by holding sockeye.

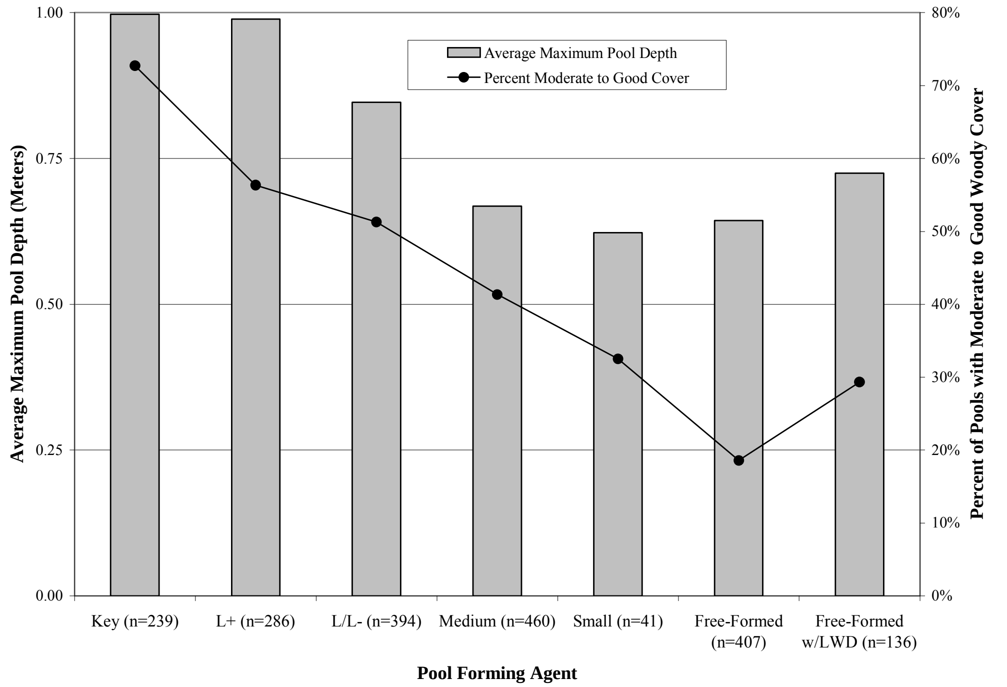

Figure 5.46. Relationship between primary pool forming agent and pool depth and cover for Ozette tributaries (source: Haggerty and Ritchie 2004).

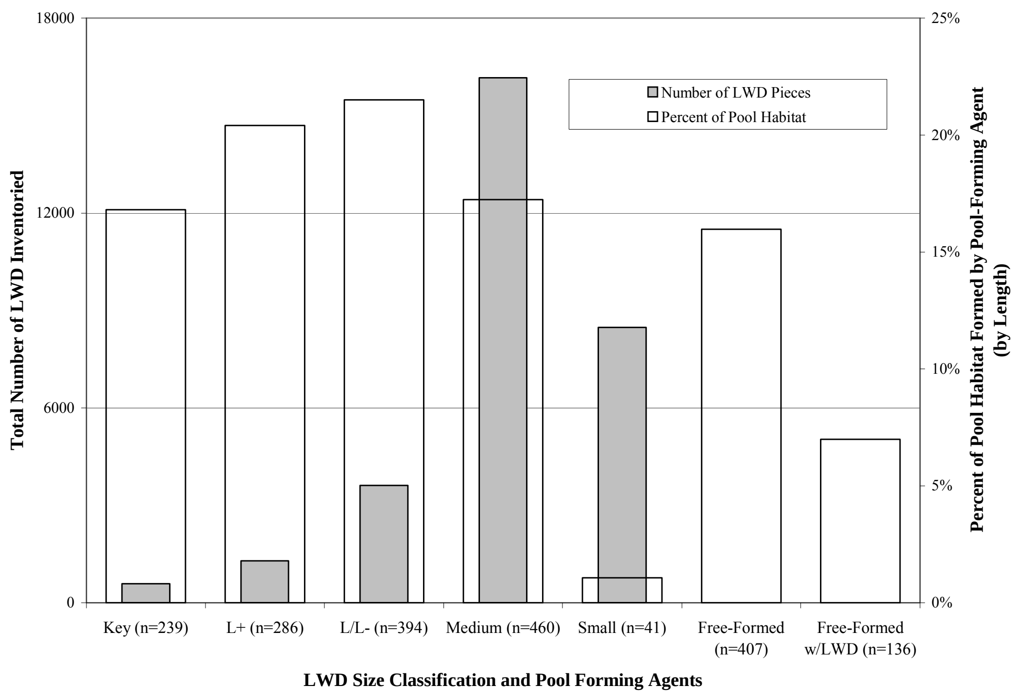

Figure 5.47. LWD piece count and percent pool habitat formed by pool forming agent for Ozette tributaries (source: Haggerty and Ritchie 2004).

5.5.4.1.2 Hydrological and Hydraulic Effects

Large woody debris (LWD) is an important frictional and roughness component in stream channels and floodplains. The roughness and turbulence created by in-channel wood is an extremely important energy dissipater in streams, aiding in channel stability (Bilby 1984; Smith et al. 1993). Large woody debris has been shown to be a major roughness element in rivers in the Pacific Northwest and around the world (Shields and Gippel 1995; Gippel 1995; Gippel et al. 1996; Dudley et al. 1998; Buffington and Montgomery 1999a; Hygelund and Manga 2003), greatly contributing to channel stability and habitat complexity. The height (stage) of water of a given discharge flowing through a channel reach is directly related to the roughness of the channel (Linsley et al. 1982; Sturm 2001), with increased wood load leading to increased stream stages. Large woody debris roughness is a major contributor in maintaining floodplain connectivity during both common and extreme flood events. Loss of wood debris and subsequent channel incision are major factors influencing the maintenance of floodplain connectivity in channels degraded by land use activities (Simon and Hupp 1992; Simon 1995; Wallerstein and Thorne 2003).

The effects of reductions in LWD in Ozette tributaries appear to have altered floodplain connectivity (Herrera 2006) and reduced floodwater storage and peak flow attenuation (Section 5.5.3). In addition, the reduction of LWD in Ozette tributaries is hypothesized to have altered in-channel hydraulic patterns around bars, bends and other roughness elements, reduced channel stability, and influenced the susceptibility of sockeye redds to scour (Section 5.5.4.3).

5.5.4.1.3 Effects on Sediment Storage and Stability

Large woody debris has been shown to be a major instream factor that influences sediment storage in forested streams in the Pacific Northwest (e.g., Nakamura and Swanson 1993). Buffington and Montgomery (1999a; 1999b) emphasize the dynamic feedback processes between water and sediment supply, sediment size, hydrologic roughness (LWD), and the provision of adequate spawning substrate (size and distribution) for salmonids. A loss of hydrologic roughness in the form of LWD was predicted to result in reach scale bed-surface coarsening and a loss of potential spawning habitat (Buffington and Montgomery 1999a), while increased sediment supply typically results in bed-surface fining in response reaches and a reduction in both spawning habitat quality and quantity (Buffington and Montgomery 1999b). In wood-rich stream reaches with increased sediment supply, wood roughness may accelerate the trapping and deposition of the finer components of bedload and result in textural fining, but will also provide increased roughness and turbulence that could keep the finer particles of the increased sediment supply in suspension. If the wood roughness also helps maintain floodplain connectivity, suspended sediment aided by wood roughness could more easily be transported out of the channel and deposited and stored on the floodplain.

5.5.4.2 Spawning Gravel Quality and Quantity

Reduced spawning gravel quality and the accumulation of fine sediment in spawning gravels during egg incubation is thought to be a limiting factor affecting the success of spawning sockeye in the watershed (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; McHenry et al. 1994; Gustafson et al. 1997; MFM 2000; Meyer and Brenkman 2001; NMFS 2003). Detailed information regarding current tributary spawning habitat conditions is included in Section 4.4.1.4, 4.4.2.4, and 4.4.3.4.

During incubation, salmonid eggs require sufficient water flow to supply egg pockets with oxygen and carry away waste products (Bjornn and Reiser 1991). Water circulation through salmon redds is a function of redd porosity, permeability, and hydraulic gradient (Bjornn and Reiser 1991). Fine sediment that settles into redds during the egg incubation period can impede water circulation and fry movement, which can result in decreased egg-to-emergence survival (Bjornn and Reiser1991). Studies throughout the Pacific Northwest have found that increased levels of fine sediment (<0.85mm) in spawning gravels decreases egg to emergence survival (Cederholm et al. 1981; Bjornn and Reiser 1991; McHenry et al. 1994). McHenry et al. (1994) found that Lake Ozette tributaries were among those with the highest proportion of fine sediment (18.7%-volumeteric equivalent) of streams sampled on the north Olympic Peninsula. Within the Ozette watershed, all sites sampled by McHenry et al. (1994) were in disturbed sub-watersheds. No control sites could be established to define un-impacted conditions draining identical geology.

However, results indicated poor gravel quality compared to either regional reference conditions or other nearby watersheds draining similar geology (McHenry et al. 1994). McHenry et al. (1994) found that coho and steelhead egg to alevin survival decreased drastically when fine sediment (<0.85mm) exceeded 13% (volumetric method) in Olympic Peninsula streams. Numerous other researchers have also found that survival to emergence relates negatively to the percentage of fines in gravel (McNeil and Ahnell 1964; Koski 1966; Cederholm et al. 1981; Cederholm et al. 1982; Tappel and Bjornn 1983; Tagert 1984; Chapman 1988).

5.5.4.2.1 Fine Sediment in Spawning Gravels

Fine sediment production has increased in the Lake Ozette watershed following European-American settlement. Changes in land use have altered disturbance regimes and replaced native vegetation age and species composition. These are considered primary factors for increased sediment production and delivery to streams (Pimentel and Kounang 1998; Opperman et al 2005). Insufficient data exist to exactly quantify the increase in the Lake Ozette watershed, although this topic is a focus of ongoing research. Current sediment production rates are estimated to be more than three times greater than pre-disturbance production rates (Herrera 2006). Herrera (2006) attributes the recent (last 50 years) increased sediment production mainly to forest practices (primarily roads and clear-cutting) and channel incision associated with LWD removal from the Ozette River.

Numerous examples of poorly designed, constructed, and maintained roads, as well as poorly designed and implemented timber harvest operations have been identified in the past (MFM 2000; Dlugokenski et al. 1981). Extensive clear-cut logging and road building have occurred within the sub-basins utilized by sockeye salmon (Umbrella Creek, Big River, and Crooked Creek; see Table 5.9).

Sediment production and delivery, and general habitat degradation in Lake Ozette tributaries from commercial forest operations have long been implicated as major limiting factors affecting salmonid survival (USFWS 1965; Phinney and Bucknell 1975; Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; WDF et al. 1994; Jacobs et al. 1996; Lestelle 1996; McHenry et al. 1996; MFM 2000; Smith 2000). Dlugokenski et al. (1981) described logging road surfacing quality as poor and noted that road surfacing literally crumbled under the weight of a loaded logging truck. They noted that during their surveys, trees were felled across Umbrella Creek and yarded through the channel; they also noted one location in the mainstem where heavy equipment had been operating in the channel. Habitat impacts inventoried and described by Dlugokenski et al. (1981) were related to forest practices conducted without regard to fish, fish habitat, or water quality. Numerous other studies from the Pacific Northwest have linked clearcut logging and associated road construction and use to increased sediment production (e.g. Brown and Krygier 1971; Megahan and Kidd 1972; Burns 1972; Farrington and Savina 1977; Beschta 1978; Cederholm et al. 1981; Cederholm et al 1982; Reid and Dunne 1984; Sidle et al. 1985; Montgomery 1994; Madej 1996; Wemple et al. 1996; Veldhuisen and Russell 1999; Lewis et al. 2001; Sidle and Wu 2001; Luce and Black 2001; Wemple et al. 2001; Brardinoni et al. 2002; Constantine et al. 2005).

No pre-disturbance fine sediment data are available for Ozette tributaries. Thus it may not be possible to exactly quantify the effects of increased sediment production on spawning gravel quality (percent fines) with 100% certainty. Dlugokenski et al. (1981) sampled fine sediment at six (6) locations (samples per location unknown) in Umbrella Creek in 1979 and found that fine sediment (<0.6 mm) averaged 17.8% (see Section 4.4.1.4). McHenry et al. (1994) sampled fine sediment in spawning gravels at three (3) locations (total n=30) in Umbrella Creek and found that fine sediment levels (<0.85 mm) averaged 16.1%. All samples from both studies were taken from the same general segment of Umbrella Creek (i.e., below the East Branch and upstream of the county bridge). The McHenry et al. (1994) data were scaled[17] to estimate wet sieve equivalent (volumetric) fine sediment less than 0.6 mm for comparing to Dlugokenski et al. (1981) data. Scaling the McHenry et al. (1994) data yielded an estimate of 12.4% fine sediment (<0.6 mm).

These data indicate that levels of fine sediment in Umbrella Creek spawning gravels contained up to 44% more fines in 1979 than in 1991. During the 10-year period prior to the 1979 gravel sampling, approximately 37% of the Umbrella Creek watershed was clearcut (MFM unpublished GIS Data). Only 7% of the watershed was clearcut during the 12 years prior to the 1991 sampling (MFM unpublished GIS Data). Fine sediment levels, depositional history at the Umbrella delta, observations by Dlugokenski et al.

[17] Scaling assumed an even distribution of sediment volume in size classes between 0.106 and 0.85 mm.

(1981) and Phinney and Bucknell (1975) of spawning gravel siltation, and logging history suggest that substantial sediment inputs occurred following a period of intensive clearcutting and road building (before 1979), resulting in very high levels of fine sediment in spawning gravels, as well as large quantities of sediment being transported downstream to Umbrella Beach spawning sites. During the period of less intensive land use in Umbrella Creek from 1979 to 1991, fine sediment levels appear to have declined from very high levels to moderately high levels.

The above examples provide evidence that past land use practices have affected the quality of spawning gravel in Ozette tributaries. High densities of roads that are hydrologically connected to the dense stream network by ditch systems, extensive clearcut logging, mass wasting, channel and bed destabilization, wood removal, decreased bank stability, windthrow, and channel incision have all increased sediment production and delivery to the stream network within the primary sockeye tributaries. Dozens of observations have been made during the last decade of sediment inputs violating State water quality standards and forest practice regulations within the primary sockeye spawning tributaries. However, changes in the proportion of fine sediment in spawning gravels in the Ozette watershed have not been quantified.

Cederholm et al. (1982) found that when logging road densities exceeded 2.9 mi/mi^2 the percentage of fine sediment in spawning gravel consistently exceeded the highest levels observed in natural undisturbed basins. Cederholm et al. (1982) also found a clear relationship between road density and percent fines in spawning gravels, which showed that on average, as road density increased, so did fine sediment levels in spawning gravels. Road density alone is not necessarily a good predictor of fine sediment levels in spawning gravels. Several factors (road type, road surfacing, road use, connectivity to stream network) influence sediment production and delivery from forest roads to streams (e.g., Luce and Black 2001). Connectivity to the stream network is related to the density of both the road and stream networks (Gucinski et al 2001). Production and delivery of sediment will not always result in measurable changes in spawning gravel composition. Rittmueller (1986) found a highly significant positive correlation between sediment yield from road surfaces and fine sediment levels in spawning gravels (e.g. a Coal Creek tributary [Dickey watershed] had the highest level of fines and the highest sediment yield from roads, and this particular road system is part the Ozette watershed).

Duncan and Ward (1985) found that for a select set of southwest Washington streams, fine sediment levels in spawning gravel were more closely correlated with soil and watershed lithology than road density, although both geology and road delivery points were positively correlated to fine sediment levels in spawning gravel. This study included only road attribute correlation tests and did not include forest attribute data or time since disturbance. In addition, while fine sediment levels were significantly different for different lithologies, the differences were relatively small compared to the range of variability of fine sediment in Pacific Northwest spawning gravels (i.e., basalt=10.02% and sandstone=11.58%). Within the Ozette watershed, McHenry et al. (1994) found no statistically significant correlation between numerous land use variables (road length, road density, forest age class, etc…) and fine sediment levels in spawning gravels. However, all Ozette tributaries contained high road densities and >80% of the tributary watershed area had been clearcut, potentially obscuring correlations between land use and fine sediment levels.

McHenry et al. (1994) suggests that marine sedimentary rock types (such as those in Ozette) are extremely friable and erode rapidly to yield sand and silt particles and could *partially* explain high levels of fine sediment found in spawning gravels. However, in undisturbed drainage basins, with similar geology, fine sediment levels rarely exceed 10% (McHenry et al. 1996). In the Dickey watershed, Coal and Skunk creeks had pre-logging fine sediment levels of 11.8% and 8.0% respectively (Samuelson et al. 1982 *In* McHenry et al. 1996). Following logging, McHenry et al. (1996) report that fine sediment levels increased to 24.7% and 18.1% in Coal and Skunk creeks respectively.

Rittmueller (1986) studied fine sediment levels in spawning gravels from streams draining the west slope of the Olympic Peninsula (from the Dickey watershed, south to the Clearwater watershed). Rittmueller found significant ($p<0.05$) positive correlations between fine sediment levels, percent watershed clearcut (Figure 5.48), and road density. Rittmueller (1986) studied streams draining watersheds with a full suite of land use histories. Watershed area clearcut varied from 0 to 80%, and road density ranged from 0 to 4.3 mi/mi^2. Watershed lithologies were the same or similar in Rittmueller's study as those found in the Ozette watershed.

Ozette sediment and percent watershed area clearcut data[18] were plotted with the Rittmueller data in Figure 5.48 for comparative purposes. Ozette data plot within the range predicted by the Rittmueller regression model. The Rittmueller data were separated into two groups, greater than 50% watershed area clearcut and less than 50% watershed area clearcut, to determine what if any differences would occur if watersheds with the most extensive clearcut history were removed from the regression analysis. Interestingly, for watersheds with >50% basin area clearcut, the same significant positive correlation could not be detected. When the McHenry data were pooled with the Rittmueller high impact watersheds (>50% clearcut), no significant relationship could be detected. However, when the McHenry data were pooled with all of Rittmueller's data, a significant ($p<0.05$) positive correlation was found. Figure 5.48 and the above discussion suggest that there may be a threshold at which road density is no longer a strong predictor of fine sediment levels.

[18] Note: Percent watershed area clearcut is an indicator of watershed disturbance and not a measure of sediment input or impact to spawning gravel. The actual quantity of sediment produced and routed into spawning gravels above "natural" background level can come from various sources and activities (roads and road use, management related mass wasting [from roads and clearcuts], clear-cutting, wet-weather log hauling, wood removal, channel and bed destabilization, decreased bank stability, management related windthrow, etc…).

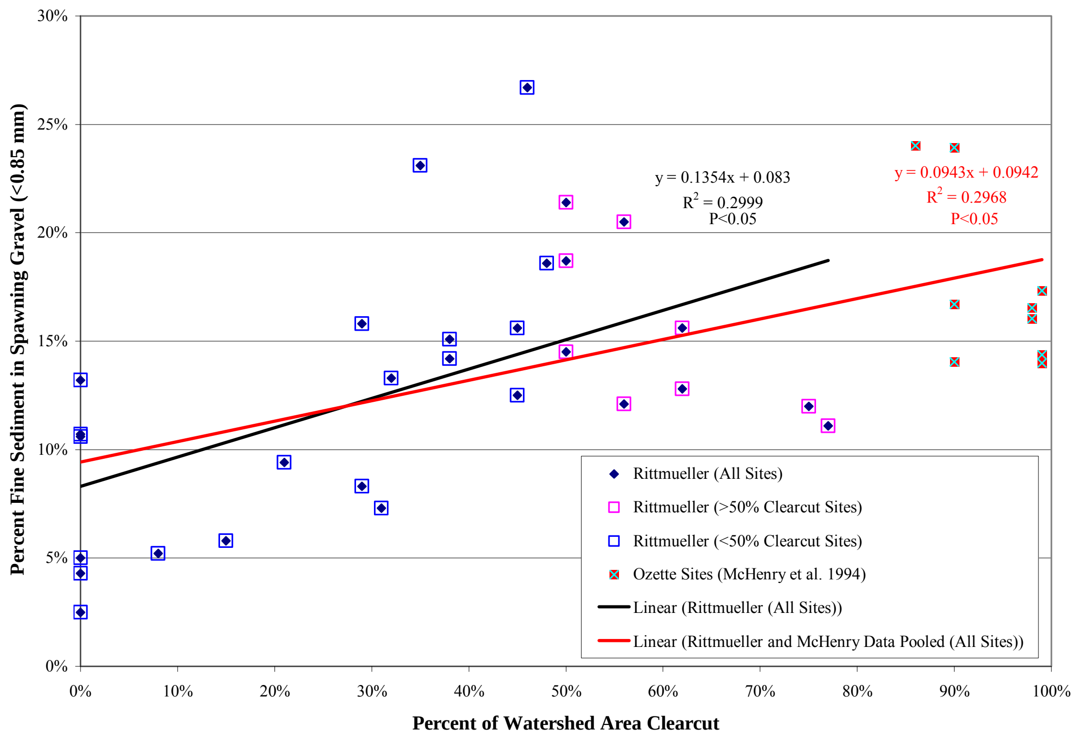

Figure 5.48. Relationship between fine sediment (<0.85 mm) in spawning gravels and percent of watershed area clearcut for Olympic Peninsula streams (source: Rittmueller 1986; McHenry et al. 1994).

Rittmueller (1986) also found a significant ($p<0.05$) positive correlation between road density and fine sediment levels in spawning gravel (Figure 5.49). Ozette fine sediment and road density data were plotted with the Rittmueller data in Figure 5.49 for comparative purposes. Ozette data plot within the range predicted by the Rittmueller road density regression model. The Rittmueller data were then separated into two road density groups, greater than 3 mi/mi^2 and less than 3 mi/mi^2, to determine what if any differences would occur if watersheds with the highest road densities were removed from the regression analysis. Interestingly, for watersheds with road densities >3 mi/mi^2 the same significant positive correlation could not be detected. When the McHenry data were pooled with the Rittmueller high road density watersheds (>3 mi/mi^2), no significant relationship could be detected. However, when the McHenry data are pooled with all of Rittmueller's data a significant ($p<0.05$) positive correlation was found. Figure 5.49 and the above discussion suggests that there may be a threshold at which road density is no longer a strong predictor of fine sediment levels.

Cederholm et al. (1982) fine sediment and road density data from the Clearwater watershed were examined to see what relationship, if any, existed between fine sediment levels and streams with high road densities. As seen with the Rittmueller data, Cederholm's high road density watersheds were found to have a poor correlation with fine sediment levels in spawning gravels. Finally all Ozette, Rittmueller, and Cederholm high road density (range 3.05 to 6.15 mi/mi^2) and fine sediment data were pooled; only a very weak correlation (r^2=0.01) could be detected (Figure 5.50).

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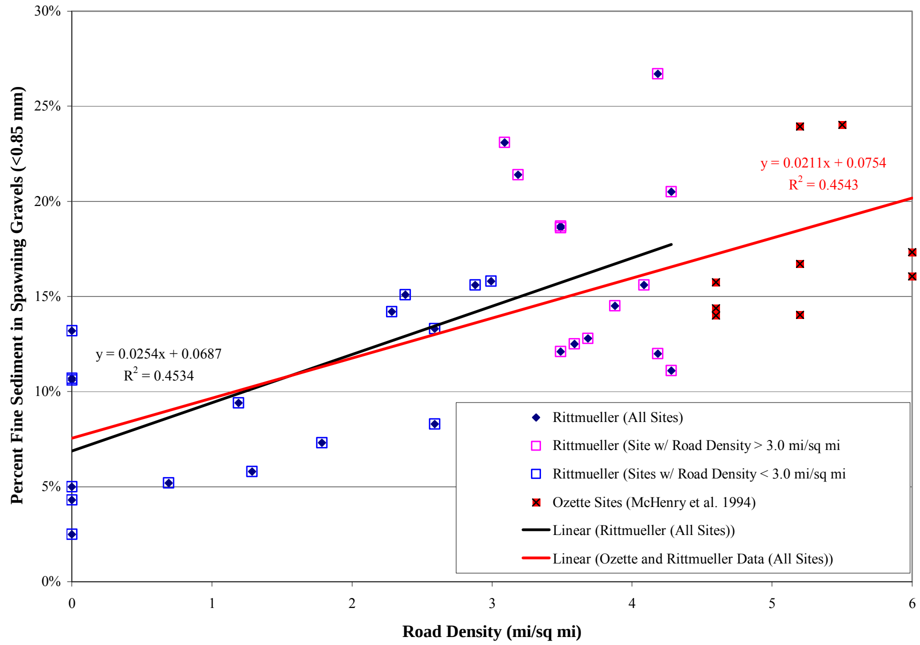

Figure 5.49. Relationship between fine sediment (<0.85 mm) in spawning gravels and road density for Olympic Peninsula streams (source: Rittmueller 1986; McHenry et al. 1994).

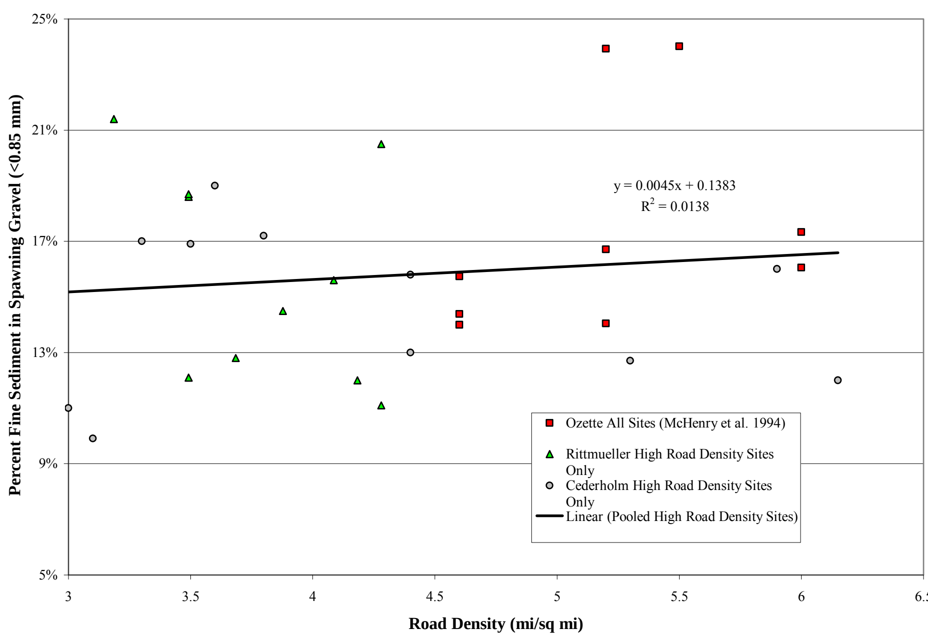

Figure 5.50. Relationship between fine sediment (<0.85 mm) in spawning gravels and road density for Olympic Peninsula and Ozette high road density watersheds (source: Cederholm et al. 1982; Rittmueller 1986; McHenry et al. 1994)

The analysis above strongly suggests that there is a threshold (~50% clearcut and road density > 3.0 mi/mi^2) at which road density and percent watershed clearcut no longer explain the variability between sites within highly disturbed landscapes. When comparing only the most heavily impacted watersheds no significant relationships between fine sediment levels in spawning gravels and road density or percent of watershed area clearcut could be found in any study conducted on the Olympic Peninsula (e.g. Cederholm et al. 1980; Rittmueller 1986). This reasonably explains why McHenry et al. (1994) were unable to find statistically significant correlations between land use variables and fine sediment levels. Key studies, such as Cederholm et al. (1982), could never have found significant relationships between road density and fines in gravel without watersheds that contained little or no roads. A clear linkage between roads and logging and their effects on spawning gravel require at least some un-impacted streams. Because fine sediment levels are moderate to high in all Ozette tributaries and there are no statistically significant relationships between land use variables and fine sediment levels, it has been suggested that fine sediment levels are naturally high and unaffected by land use. While it may never be possible to exactly determine the amount that fine sediment levels have increased in Ozette tributaries due to land use with 100% certainty, it would be illogical to dismiss the preponderance of evidence that indicate that sediment production and delivery to the stream network has dramatically increased and this increased sediment production has degraded spawning gravel conditions. Many factors may ultimately regulate fine sediment levels in spawning gravels, but clearcut logging and logging roads are thought to be the primary source of increased fine sediment levels in Ozette tributaries.

5.5.4.2.2 Decreased Number of Suitable Spawning Habitats

Past estimates of available spawning habitat area in the mainstem of Big River and Umbrella Creeks range from 46,000 (Dlugokenski et al. 1981) to 60,000 (Blum 1988) sockeye. Currently, tributary run sizes average less than 5,000 spawners total, and therefore Lake Ozette tributary spawning sockeye do not appear to be limited by available spawning habitat. However, the quantity of suitable spawning habitat area in Ozette tributaries is thought to have been reduced due to the effects of gravel mining, wood removal, reduced wood abundance, channelization, bank armoring, increased fine sediment inputs and abundance, and colonization of bar deposits by non-native vegetation. No attempts to quantify available spawning habitat have been conducted in recent years but a complete inventory of LWD and pool habitat conditions revealed that several reaches that had low LWD levels also had correspondingly coarser sediment than preferred for spawning salmonids.

Significant correlations between the surface area of sediment accumulations and LWD volume have been shown for streams draining old-growth forests in western Washington (Bilby and Ward 1989). Beechie and Sibley (1997) studied streams draining second-growth forests and found no correlation between percent gravel (percent of habitat with dominant gravel substrate, 16-64 mm) and LWD/m, LWD volume/m, or LWD volume/m^2. They speculated that debris volumes within their survey sites may have been too low to see a correlation between percent gravel and LWD debris volumes. In old-growth Alaskan streams, Martin (2001) found that gravel dominance within habitat units increased with both increased LWD frequency and volume. Bilby and Ward (1991) found that streams draining old-growth forests had larger areas of LWD-associated sediment accumulations than those found in streams draining second-growth forests.

Kramer (1953) described the Big River as having almost a continuous bed of gravel from the Hoko-Ozette Road Bridge to about a mile from the mouth. Substrate conditions in this stream reach were described as mostly sand and pebbles with occasional gravel patches by Haggerty and Ritchie (2004), a result of sedimentation from upstream. The quantity of lost suitable spawning habitat due to sedimentation, gravel mining, vegetation encroachment, bank armoring, and channel incision has not been thoroughly investigated.

5.5.4.3 Channel Stability (Scour)

Gravel scour in Ozette tributaries has been described as a limiting factor affecting salmonid survival (MFM 2000; Meyer and Brenkman 2001). While numerous observations have been made of highly mobile stream beds in tributary spawning areas, no direct monitoring of scour depth has been conducted in Lake Ozette tributaries. Relative to other life history stages, the gravel incubation and alevin rearing periods are critical to population levels, as a majority of individuals perish during them (Quinn 2005). Channel stability and scour are important factors influencing embryo survival incubating in gravel. Channel stability is influenced by many factors, including streamflow, sediment inputs, sediment transport imbalances, bed and bank material, size and density of LWD, and channel-floodplain connectivity. The survival of incubating salmonid embryos in gravel-bed rivers is sensitive to changes in bedload scour depth associated with floods, in addition to fine sediment levels (Seegrist and Gard 1972; Erman et al. 1988; Tripp and Poulin 1986; Montgomery et al. 1996; DeVries 2000; Schuett-Hames et al. 2000; Haschenburger 1999; Lapointe et al. 2000; McNeil and Ahnell 1964; Everest et al. 1987; Reiser and Bradley 1993; McHenry et al. 1994).

In Washington State, several studies of juvenile salmonid emigration or returning adult abundance have been related to flood magnitude during the previous incubation period, often with strong correlations (e.g., Seiler et al. 2001; Ames and Beecher 2001; Green et al. 2005). For example, Seiler et al. (2001) estimated that for common floods (0.5- to 2-year RI) during the Chinook incubation period, egg to migrant fry survival was approximately 15%. Egg to migrant fry survival dropped below 10% during larger floods (> 10-year RI), and survival was extremely low (<5%) during floods greater than the 50-year RI. Bedload scour is hypothesized to be the leading cause of mortality for reduced survival, but other factors such as fine sediment intrusion associated with streambed scour or reduced holding or feeding opportunities following emergence could also be confounding factors.

Bedload scour data from Washington State indicate that only modest changes in the magnitude of common peak flow events (0.5- to 2-year RI) from land use or climate change could significantly alter the frequency and depth of bedload scour and influence the survival of incubating salmonid embryos in gravel bed rivers (Montgomery et al. 1996; Shellberg 2002). Beamer and Pess (1999) and Pess et al. (2000) documented a significant increase in peak flow magnitude for the North Fork Stillaguamish River between 1928 to 1995, which was largely attributed to observed land use trends (increased road density and hydrologic immaturity over the period of record), and only partially attributed to climate variability (36% of variation). Using egg to fry survival and recruitment ratio data from the Skagit and Stillaguamish Rivers, Beamer and Pess (1999) estimated that a 25% increase in the 2-year RI flood has reduced egg to fry survival from 10% to 5%, with extremely low recruitment during floods greater than the 10-year RI under altered hydrologic conditions. In addition, variable streamflow (natural or anthropogenically enhanced) during the spawning and incubation period can result in reduced probabilities of successful egg-to-fry survival, by forcing salmon to spawn either high on the channel margins (increased desiccation and sediment entombment probability) or low in the channel thalweg (increased scour probability) (Ames and Beecher 2001; Lapointe et al. 2000; see Section 5.5.1.3).

For Ozette tributary sockeye, it is hypothesized that the combined influence of increased common peak flood magnitude, increased sedimentation of spawning reaches, reduced wood loads, and/or channelization and floodplain disconnection have synergistically destabilized relative bed stability and reduced sockeye egg to fry survival. In urban and agricultural areas, channel stability has been shown to decrease with increasing watershed disturbance and development (Booth 1990; Booth and Jackson 1997). In watersheds subject to forest harvest and road building, relative bed stability has been shown to decrease with increasing watershed and riparian disturbance, with greater changes in bed stability in basins underlain by weak sedimentary rock or with high road densities (Tripp and Poulin 1986; Faustini and Kaufmann. 2003), similar to the Ozette watershed. Channel stability is reduced as waves of bedload sediment move through the channel network from hillslope landslide failures associated with roads and other land use (Madej 1996; 1999) and local sediment transport imbalances can significantly affect the magnitude of scour and fill (Lisle et al. 2000). Salmonids spawning reach and site selection is often correlated with abundant LWD and cover (e.g., Merz 2001). Bed stability has been shown to decease following wood removal (Bilby 1984; Smith et al. 1993). Redd scour to the depth of salmonid egg pockets has been shown to be reduced in reaches or sites with abundant large stable LWD (Shellberg 2002), and increased in reaches with smaller mobile LWD (Schuett-Hames et al. 2000). Channelization can severely destabilize the vertical and horizontal stability of gravel and sand bedded channels (Cederholm and Koski 1977; Simon and Hupp 1992; Simon 1995).

For mass spawning fish (e.g., chum [or sockeye]), Montgomery et al. (1996) hypothesize from theoretical calculations that gravel coarsening from the act of mass redd construction could significantly reduce the mobility of the gravel bed and thus reduce scour depth. In addition, gravel cleaning and coarsening by mass spawning fish at least *temporarily* (i.e., several weeks) (Kondolf et al. 1993; Peterson and Quinn 1996) reduces the fine sediment levels in the bed and redd (Kondolf and Wolman 1993; Kondolf et al. 1993), increasing egg to fry survival. The reduction of mass spawning fish populations such as sockeye from other limiting factors could be further impacted by the negative feedback of reduced gravel bed maintenance of fine sediment levels or scour depths (Montgomery et al. 1996).

Since data are lacking in Ozette regarding 1) scour depths at sockeye redds, 2) the effects of flood peak magnitude on scour depths, 3) and the other factors mention above that affect scour, no quantitative conclusions can be made regarding the impact on sockeye egg to fry survival. The above-mentioned hypotheses and physical processes need to be tested in Ozette tributaries in order to understand the relative importance of each separate or cumulative effect on scour and sockeye egg to fry survival. Thus, scour and bed stability remains a critical data gap.

While direct gravel scour data are lacking, indirect evidence from the December 15, 1999[19] flood is available. Peak sockeye counts in Umbrella Creek for RY 1999 were recorded on November 29 (MFM unpublished spawning ground survey data). Peak spawning is thought to have occurred around this date. It was estimated that 1,477 sockeye spawned in Umbrella Creek in 1999 (see Section 3.5.2). Adult returns in 2003 were estimated to be 1,740; no BY 1999 hatchery sockeye were released into Umbrella Creek. It has been estimated that 1.2 sockeye returned to spawn in Umbrella Creek in 2003 for each sockeye that spawned in 1999. However, this example does not indicate that scour is not a problem in Ozette tributaries. Incubation flows following the December 15, 1999 flood event were ideal for incubating sockeye and it is unclear what proportion of the RY 2003 sockeye run were progeny of fish spawning after December 15, 1999 or before. These observations suggest that sockeye survival in Umbrella Creek, in a year with at least one extreme peak flow event, was high enough for sockeye to replace themselves. Scour data are considered an important data gap for Ozette tributaries and it is important to understand how scour may affect sockeye salmon's ability to utilize tributaries such as Umbrella Creek and Big River into the future.

5.5.5 Predation

Predation on juvenile and adult sockeye in Ozette tributaries is poorly documented. Known predators in the tributaries include: sculpin, juvenile coho, cutthroat trout, river otters, harbor seals, black bears, bob cat, cougar, and bald eagles (Gearin et al. 2002; MFM unpublished trap data). Other potential predators include northern pikeminnow, juvenile rainbow trout/steelhead, various bird species (osprey, merganser, belted-kingfisher), and other terrestrial mammals. No studies have been conducted exclusively focusing upon potential impacts of predators in Lake Ozette tributaries. Brief descriptions of sockeye predation by life history stage in Lake Ozette are included below.

A complete description of adult sockeye entering, migrating, and holding in Lake Ozette tributaries can be found in Section 3.1.3. During the period that adult sockeye enter,

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[19] The December 15, 1999 flood event is thought to have a recurrence interval of about 50 years. Flow data are not available for Ozette tributaries during this event, but Hoko River discharge was estimated to be ~20,000cfs, and the resulting Lake Ozette lake level was the highest ever recorded.

migrate, and hold in lake tributaries they are primarily susceptible to predation by river otters, harbor seals, and terrestrial mammals. Gearin et al. (2002) observed a harbor seal chasing sockeye staging off of the mouth of Umbrella Creek during predator surveys in 2000. No direct seal predation events were observed by Gearin et al. (2002). Hughes et al. (2002) concluded that there is very little evidence of pre-spawning predation mortality in Umbrella Creek based on tagging, tracking, genetic sampling, and spawning ground surveys. In 2000, seven adult sockeye tagged with CART tags were tracked in Umbrella Creek and all were observed to have successfully spawned. A cougar was observed trying to take spawning sockeye in Umbrella during the winter of 2000 (MFM unpublished spawning ground survey data).

During spawning and egg incubation, sockeye eggs are susceptible to predation by sculpin, cutthroat trout, and, potentially, river otters. No attempt to measure sockeye egg predation in the tributaries has been conducted nor has it been suggested that significant levels of egg predation are occurring. Within other sockeye populations, many observations of egg feeding by predatory fishes and birds on eggs have been made, but most observers have concluded that the bulk of eggs eaten are dislodged by late-arriving spawners and would have had a low chance for survival (Foerster 1968; Burgner 1991). In a general review of sockeye salmon life histories, Burgner (1991) concluded that less is known about predation on eggs and alevins in the redds than at other life stages, but physical and chemical factors such as redd desiccation, freezing, lowered DO resulting from siltation, reduced flow, and dislodgement (scour or superimposition) are probably more important as mortality factors.

Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in tributaries. Burgner (1991) reviewed several studies conducted to determine fry predation rates for riverine spawned sockeye fry emigrating to nursery lakes and found widely ranging values: 63%-84% (Scully Creek, Lake Lakelse, 4 yrs), 66% (Six Mile Creek, Babine Lake, 1 yr), 13%-91% (Karymaiskiy Spring, Kamchatka Peninsula, 8 yrs), and 25%-69% (Cedar River, Lake Washington). Burnger (1991) concludes that while these sockeye fry predation rates may not represent the potential range of predation, they do indicate that predation losses can be extensive. No studies have been conducted to estimate emergent sockeye fry predation in the Ozette tributaries. However, fyke net trapping during and after hatchery sockeye fingerling releases was conducted in 1999 (BY 1998) and 2002 (BY 2001). In 1999, only 33% of the sockeye fingerlings released at RM 4.7 were recaptured in a fyke net stationed at RM 0.8; this suggests a 26%-60% (trapping efficiency ranged from 44.8% to 82.4%) instream mortality (from MFM 2000). Potential predators at this life history stage include sculpin (sp), cutthroat trout, juvenile steelhead trout, and juvenile coho salmon. Predator interactions at this early life history stage remain a data gap and it is possible that significant levels of predation occur in Umbrella Creek and Big River.

5.5.5.1 Predators

5.5.5.1.1 Harbor Seals (Phoca vitulina)

The small size of Lake Ozette tributaries appears to limit harbor seal distribution to the lower reaches of the tributaries. Gearin et al. (2002) observed a harbor seal move upstream from the mouth of Umbrella Creek, but they were unable to determine how far it went. Most harbor seal predation is likely limited to sockeye staging near the mouth of tributaries and in the lower reaches of tributaries.

5.5.5.1.2 River Otters (Lutra canadensis)

No specific data exists regarding the number of otters or the number of adult sockeye preyed upon by river otters in Lake Ozette tributaries. As described above, there is no evidence of significant levels of predation occurring on adult sockeye in Lake Ozette tributaries.

5.5.5.1.3 Native Fish Species

Native species known or believed to prey upon emigrating sockeye fry in the tributaries include: sculpins (sp), juvenile steelhead/rainbow trout, cutthroat trout, and juvenile coho salmon. During fry trapping studies in Umbrella Creek, sculpin appeared to selectively feed on swim-up sockeye fry inside the live box independent of fry density. Coho fry outnumbered sockeye 10.4 to 1 but were consumed at a ratio of 1.2 to 1; sockeye were nine times more likely to be consumed by sculpins than coho within the live box (MFM, unpublished trapping data). MFM (2000) postulated that higher predation rates on sockeye fry over coho fry may have been due to the sockeye's behavior of remaining motionless in the substrate within the trap where sculpin were also present.

During trapping studies in Umbrella Creek, salmonid stomachs were not sampled, but sockeye fry were thought to be consumed by juvenile steelhead, cutthroat trout, and coho pre-smolt and fry. Coho fry as small as 1.5 inches (35-40mm) were observed preying upon sockeye fry in the trap live box. In the Cedar River, sockeye fry migrating to Lake Washington constituted 2 to 52% wet biomass of steelhead smolt diets and averaged 13% of their diet from February through mid-May (Beauchamp 1995). Bioenergetics simulations indicated that under the "normal" scenario 15% of the emergent fry production was consumed by steelhead smolts.

5.5.5.1.4 Introduced Fish Species

Introduced fish species have not been observed in Lake Ozette tributaries, but species such as largemouth bass may prey upon emigrating sockeye fry in the lower reaches of Big River, Umbrella Creek, and Crooked Creek.

5.5.5.2 Factors Affecting Predation

5.5.5.2.1 Large Woody Debris and Stream Habitat Conditions

The relationship between LWD and predator avoidance with respect to sockeye salmon is poorly documented in the general sockeye literature. Habitat and LWD data collected in Ozette tributaries clearly shows a linkage between pool habitat quality and complexity and large wood. Haggerty and Ritchie (2004) found that on average the deepest pools with the most cover complexity were most often associated with the pools formed by key-piece-sized LWD. It is assumed that the deepest pools with the greatest cover and complexity likely provide the best predation refuge habitat for pre-spawning adult sockeye. Holding pool frequency and overall pool habitat quality was evaluated for Umbrella Creek, Big River, and Crooked Creek by Haggerty and Ritchie (2004) and their results are included in Figure 4.49, Figure 4.59, and Figure 4.69. The relationship between LWD and sockeye fry predator avoidance is even less clear than with respect to holding adult sockeye. Sockeye fry appear to move mostly during twilight hours or during nighttime. They appear to move downstream mostly along the margins of the channel and have not been observed holding in pools during daylight hours. It is thought that tributary sockeye fry burrow into the stream substrate during daylight hours and therefore the importance of LWD for cover and predator avoidance is less than for other salmonid species (such as coho salmon). Substrate conditions such as embeddedness may play a more important role for sockeye fry in predator avoidance than LWD in Lake Ozette tributaries.

5.5.5.2.2 Increases in Regional Pinniped Population

See Sections 5.2.2.2.1 and 5.3.4.2.2.

5.5.5.2.3 Abandonment of Ozette Village

See Section 5.2.2.2.2

5.5.6 Competition

Within Lake Ozette tributaries, competition is limited primarily to spawning, since emergent sockeye fry quickly migrate to the lake upon emergence from the gravel. Both intraspecific and interspecific competition are apparent in tributaries to the lake, as sockeye competing with one another for spawning habitat, sockeye competing and/or spawning with kokanee for spawning habitat, and sockeye competing with coho salmon for spawning habitat. The degree and type of competition thought to occur in tributaries varies by stream system. Within Umbrella Creek, spawning competition for suitable spawning sites and mates is more intense than in Big River and Crooked Creek. In recent years, large numbers (1,000 to 4,000) of spawning sockeye use habitat in a fairly discrete section of Umbrella Creek; most spawning takes place in a 2.2-mile-long section of the stream. Competition within this reach can be intense and redd superimposition plays a significant role in determining the number of fertilized eggs that ultimately make it into the spawning gravels to incubate.

During the peak spawning period, downstream of mass-spawning areas in Umbrella Creek, hundreds of sockeye eggs can be seen along the bottom of the stream or being transported downstream. The degree of redd superimposition likely varies depending upon the number of spawners returning to Umbrella Creek, as well as how they distribute themselves during the spawning period. Some spawning competition with coho salmon must also occur since both species spawn during at the same time and in the same habitat (although must coho spawning appears to occur in the upper mainstem and tributaries to Umbrella Creek). If the coho population size continues to increase there is expected to be increased competition between coho and sockeye salmon for suitable spawning habitat. Competition and interaction with kokanee is thought to be minimal in Umbrella Creek since few kokanee spawn in this stream system. However, sockeye spawning with kokanee-size *O. nerka* in Umbrella Creek has been observed and documented on several occasions (Figure 5.51).

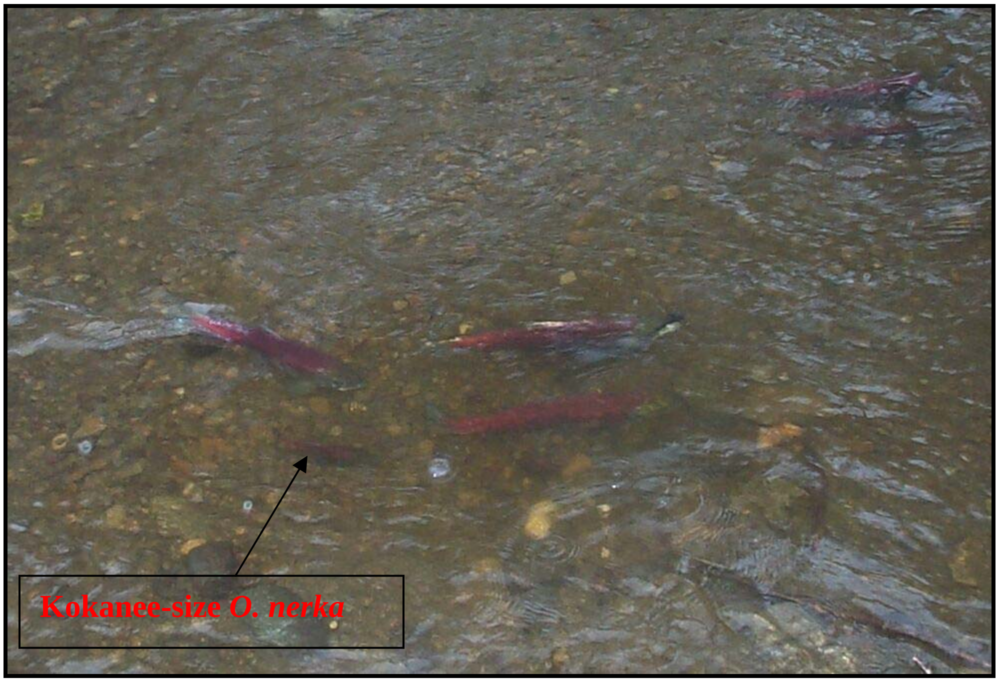

Figure 5.51. Example of kokanee-size *O. nerka* spawning with adult sockeye (source: MFM photo archives).

Within Big River the current size of the spawning run is small relative to Umbrella Creek and intraspecific competition of spawning sites is thought to be much lower than in Umbrella Creek. However, if the Big River spawning aggregation grows considerably, then intraspecific competition for suitable habitat should increase. Some Big River sockeye spawning occurs during the same time and within the same habitat as coho spawning, and therefore some competition for suitable habitat between these species must occur. Much of the Big River coho spawning occurs in the upper mainstem and in tributaries such as Boe, Solberg, and Trout Creeks, which may act to minimize interspecific competition with sockeye salmon. Kokanee spawning in the mainstem of Big River is very rare. A review of nearly 200 spawning ground surveys (1970-2005) conducted in the mainstem of Big River during the kokanee spawning season yielded only one observation of kokanee, and these fish were not observed spawning.

The exact number of sockeye spawning in Crooked Creek is unknown, but is thought to be relatively low based upon spawning ground survey data collected from 1999 through 2004. Kokanee abundance is far greater than sockeye abundance; peak kokanee counts per mile averaged 100-500 during years with complete surveys (see Figure 2.1). Competition and interaction with kokanee in Crooked Creek is expected to be fairly common. Kokanee spawn timing is slightly earlier than observed sockeye spawn timing and may act to minimize interaction and gene flow between these populations. Spawning ground data from Crooked Creek suggest that both coho salmon and kokanee out number sockeye, but coho spawning densities are not thought to exceed the habitat carrying capacity in this stream system. Hatchery releases into Crooked Creek no longer occur because of concerns over sockeye-kokanee interactions and the fact that the two groups represent discrete populations of *O. nerka.*

5.5.7 Hatchery Broodstock Collection

Hatchery broodstock collection from Umbrella Creek was first conducted in 2000 (MFM 2000). In the first year, broodstock were collected using dip and gill nets in the mainstem of Umbrella Creek. Starting in RY 2001, all sockeye broodstock were collected at the Umbrella Creek weir (RM 0.8). Broodstock collection protocols are intended to minimize negative impacts to naturally spawning Umbrella Creek sockeye (MFM 2000). Broodstock are selected randomly and representatively from the total return to Umbrella Creek and include both natural-origin and hatchery-origin sockeye (MFM 2000). Broodstock collection protocols limit the number of sockeye retained at the weir in order to protect against population diversity losses in both naturally and hatchery spawned sockeye. Broodstock collection is limited to 40 pairs when Umbrella Creek run size is less than 533, and all progeny are to be released into Umbrella Creek. When the run- size is greater than 533, up to an additional 60 pairs may be collected in Umbrella Creek for use in Big River; total broodstock collection cannot exceed 15% of the run size (MFM 2000). Since 2000, broodstock collection has ranged from 11.4% to 4.8% of the total run size, averaging 7.5% (MFM, Unpublished broodstock collection data).

5.5.8 Disease

Tributary spawning ground surveys during the last 10 years have provided no evidence of pre-spawning disease-induced mortality in the tributaries. If disease-related pre-spawning mortality of tributary spawning sockeye occurs at significant levels, then it must occur in the lake and therefore go undetected in the tributaries.

5.6 OFF-SHORE MARINE ENVIRONMENT

5.6.1 General Marine Survival

As described in Section 3.5, limited marine survival data indicate that *total* marine survival rates appear good, averaging 15-27% (brood years 1988, 1990, and 2000; see Section 3.5). While these data are limited (3 years; questionable accuracy), they do suggest, at least for the brood years estimated, that marine survival has had limited influence on the recent low abundance of Lake Ozette beach spawning aggregations. Also note that the 15.5% survival for BY 2000 is survival from smolt to spawner and includes pre-spawning holding mortality in the lake. Koenings et al. (1993) summarized average marine survival rates for sockeye salmon based on geographic location and smolt size. Large sockeye smolts (>115mm) in the southern range (latitude <55°N) averaged 17.1% marine survival (this estimate was primarily derived from Lake Washington sockeye survival estimates). This provides further evidence that marine survival estimates for Ozette sockeye are within the range expected for the stock.

In recent years, fisheries biologists have speculated that temporarily poor ocean conditions contributed to the decline of Ozette sockeye (Jacobs et al. 1996; MFM 2000). The major decline for Ozette sockeye can broadly be described as occurring from 1948-1978. This time period roughly corresponds to a period of low productivity for Bristol Bay sockeye stocks (Peterman et al. 1998). The abundance of Fraser River sockeye in the 1960s was low, and increased to high levels in the 1980s. Increases were attributed to climatic regime shift starting in the winter of 1976-77 (Beamish et al. 1997). However, Peterman et al. (1998) suggests that decadal-scale environmental changes that occurred in the mid-1970s mainly improved productivity for northern sockeye stocks (particularly Bristol Bay stocks), while effects on southern stocks were on average much smaller and more variable among stocks. In addition, in a recent review, Pyper et al. (2005) found "*no evidence that broad, ocean-basin-scale environmental processes simultaneously influenced survival rates of pink, chum, and sockeye salmon across the regions of the northeast Pacific…*".

While marine survival is a critical component in determining the ultimate abundance of Lake Ozette sockeye, broad-scale, regional studies of decadal-scale productivity suggest that changes in marine survival played a limited role in the decline of Ozette sockeye.

5.6.1.1 Interception and Harvest

No marine harvest data for Lake Ozette sockeye exist. In order to understand how marine harvest might affect Lake Ozette sockeye, information from nearby sockeye stocks were used to estimate Lake Ozette sockeye marine spatial and temporal distributions. Marine area migration timing for Lake Ozette sockeye salmon was estimated for Southeast Alaska (SEAK) and West Coast Vancouver Island (WCVI) marine areas. Migration timing estimates were back-calculated from 1998-2003 mean daily lake entry timing data developed by Haggerty (2005d). A coastal area migration rate of 32 miles per day was estimated for migrating Fraser River sockeye salmon (Jim Cave, Pacific Salmon Commission, pers. comm. with Tim Tynan NMFS, January 5, 2006; Quinn 1988). Combining migration rates with nautical distance, estimates were applied to lake entry timing data to approximate Ozette sockeye abundance and timing in northern marine approach areas (Figure 5.52). A near-coastal migration rate similar to that observed for early migrating sockeye salmon (e.g. Early Stuart Stock) was assumed, as was a northern land-fall along the southeast Alaskan coast (Figure 5.53). Lake Ozette sockeye are assumed to enter freshwater without delay after arriving at the river mouth, similar to Early Stuart sockeye (i.e. lake entry and arrival at the river mouth assumed to be equal).

Recent periods were identified when the major West Coast marine area sockeye-directed fisheries occurred in Southeast Alaskan marine waters (District 104 purse seine fisheries; Figure 5.54) and in Canadian West Coast Vancouver Island areas (Areas 121-127 troll fisheries; Figure 5.55). These data and periods were derived from Pacific Salmon Commission Northern Boundary Committee and Fraser Panel annual reports.

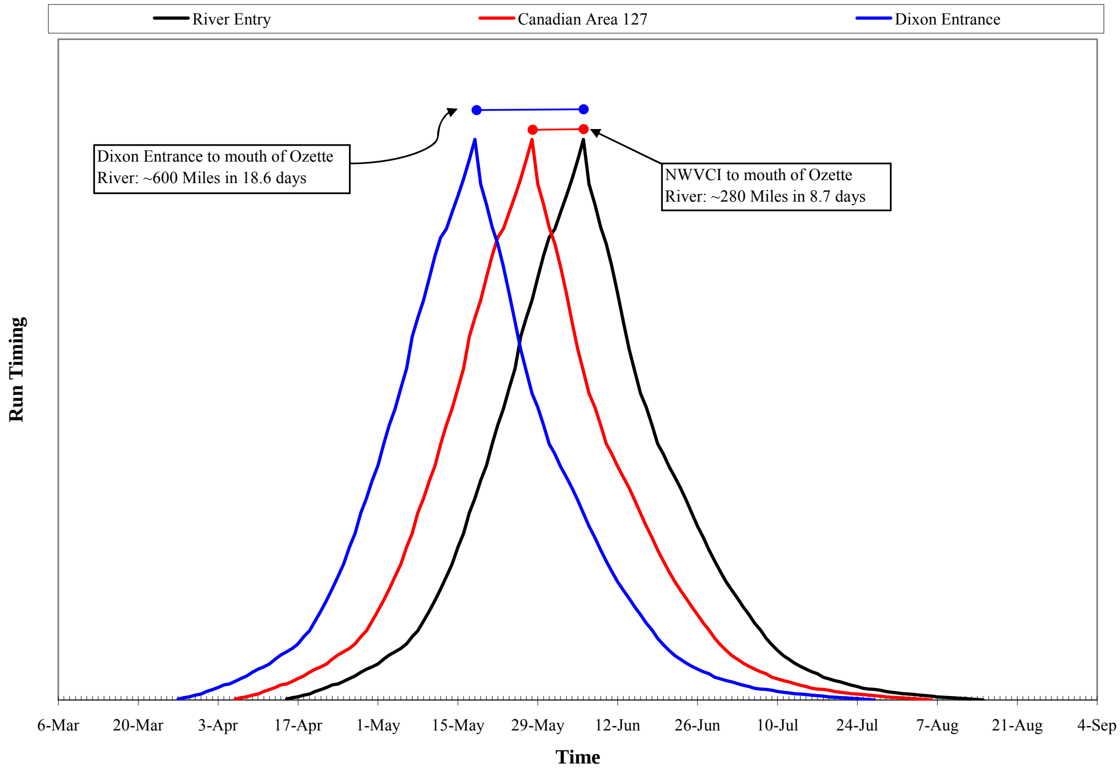

Figure 5.52. SEAK (Dixon Entrance) and North WCVI (Canadian Area 127) marine area timing estimates back-calculated from 1998-2003 average run timing, assuming rate of 32 miles per day and applied to distances from Ozette River.

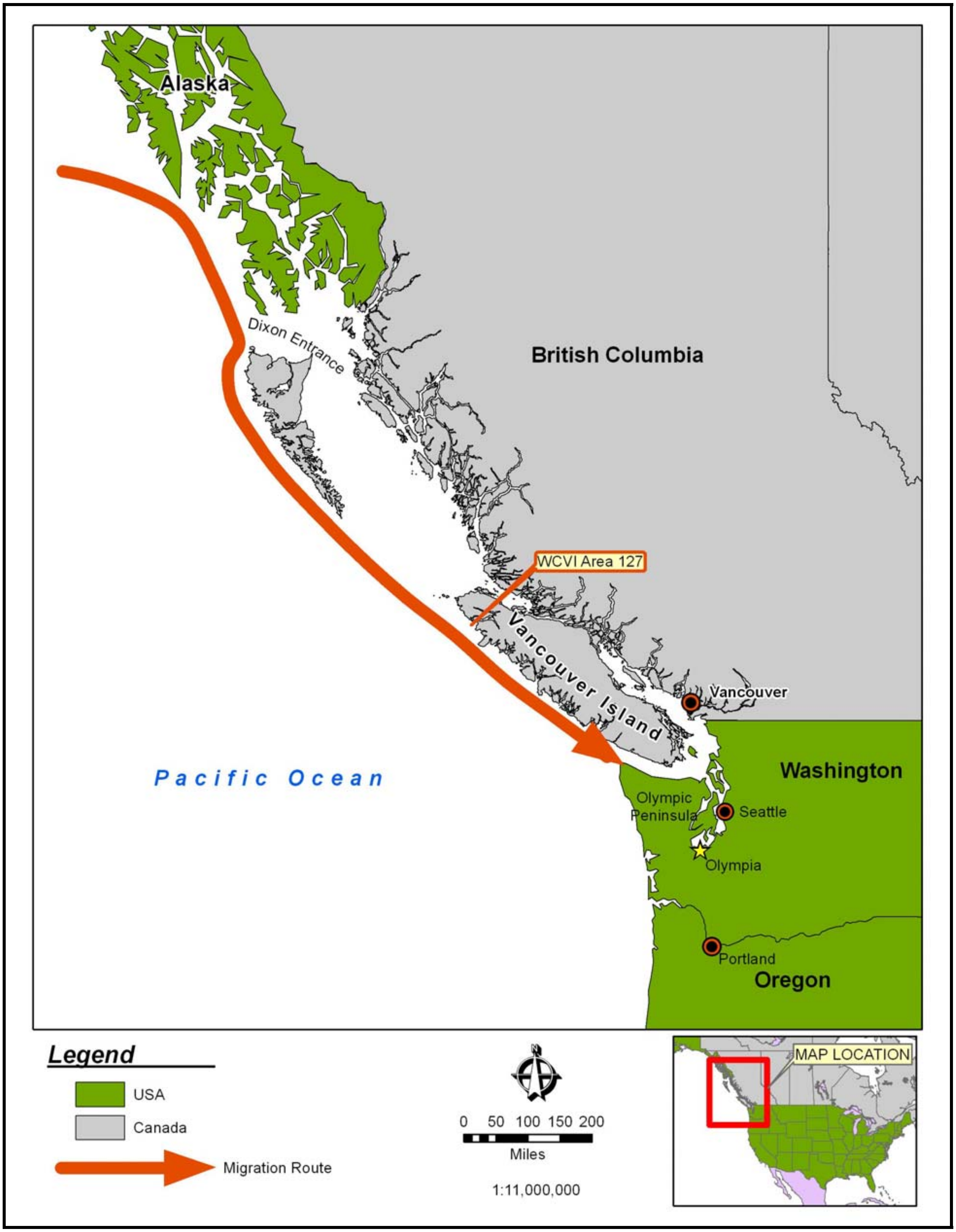

Figure 5.53. Assumed Lake Ozette sockeye ocean migration route.

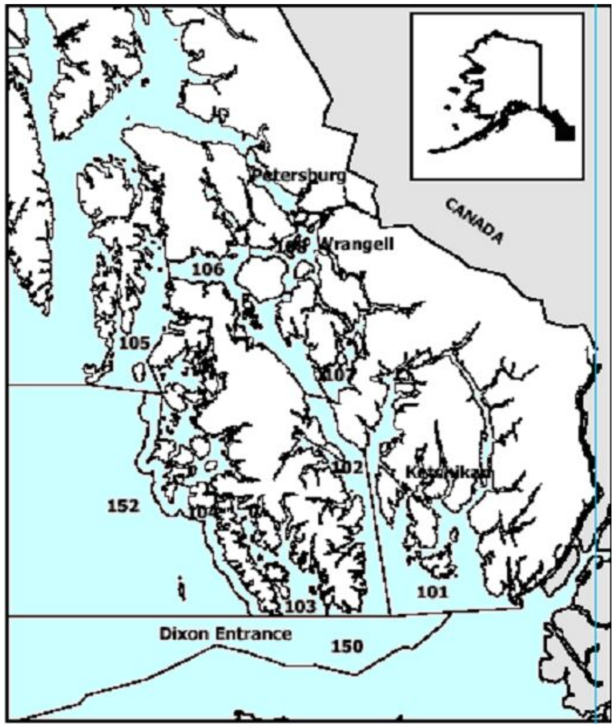

Figure 5.54. Alaska Department of Fish and Game southern Southeastern Alaska regulatory districts.

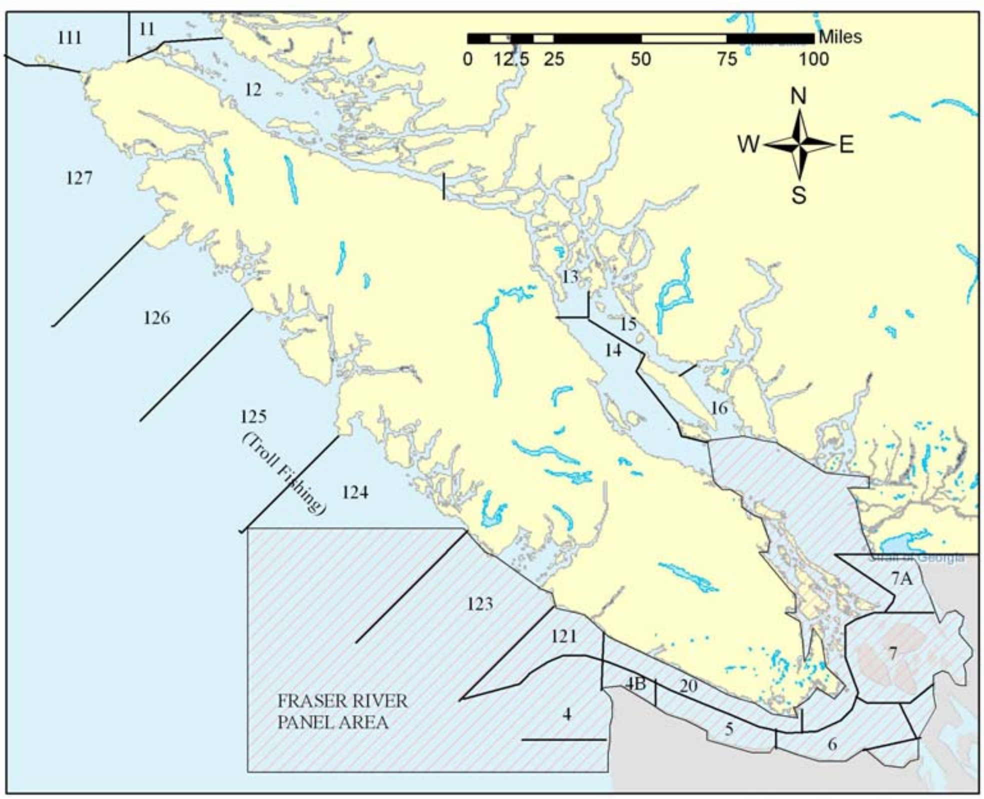

Figure 5.55. British Columbia and Washington State fishery management areas, including Fraser River Panel Area (boundaries and units are approximated).

Charts were assembled to compare Ozette sockeye migration timing with the timing of fisheries in recent years to determine whether the fisheries could be intercepting Ozette sockeye (Figure 5.56 and Figure 5.57). Purse seine fisheries in Alaska District 104 (Figure 5.54), directed at Southeast Alaska-origin pink salmon (and Skeena/Nass sockeye stocks), intercept inbound Fraser River sockeye in some years at significant levels. However, fisheries in District 104 have not commenced until early July in recent years, with peak sockeye catches occurring in early August. The fishery appears to occur too late in the season to pose a substantial threat of interception to Ozette sockeye (Figure 5.56).

Sockeye-directed troll fisheries occurring in West Coast Vancouver Island (WCVI) Areas 121-127 (Figure 5.55) harvested significant numbers of Fraser River sockeye salmon in the 1980s and early 1990s. However, this fishery has been virtually closed since 1996 for domestic allocation purposes. The estimated timing of Ozette sockeye salmon migration in the WCVI troll fishing areas would indicate that less than 10% could be subject to harvest in troll fisheries (Figure 5.57). The PSC Area 20 (Figure 5.55) gillnet test fishery commencing on or about June 21 each year may also intercept Ozette sockeye. Area 20 is approximately one day’s travel from the mouth of the Ozette River. Approximately 25% of run could be subject to harvest in the Area 20 test fishery (Figure 5.57).

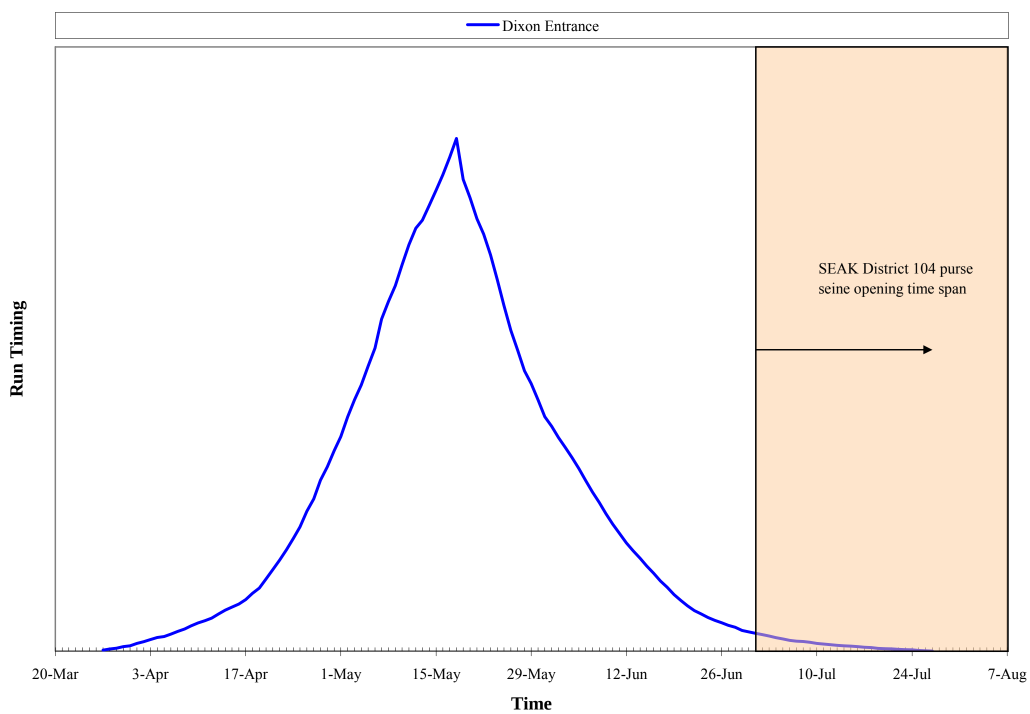

Figure 5.56. Estimated Lake Ozette sockeye Dixon Entrance migration timing compared with recent SEAK D104 purse seine opening time span.

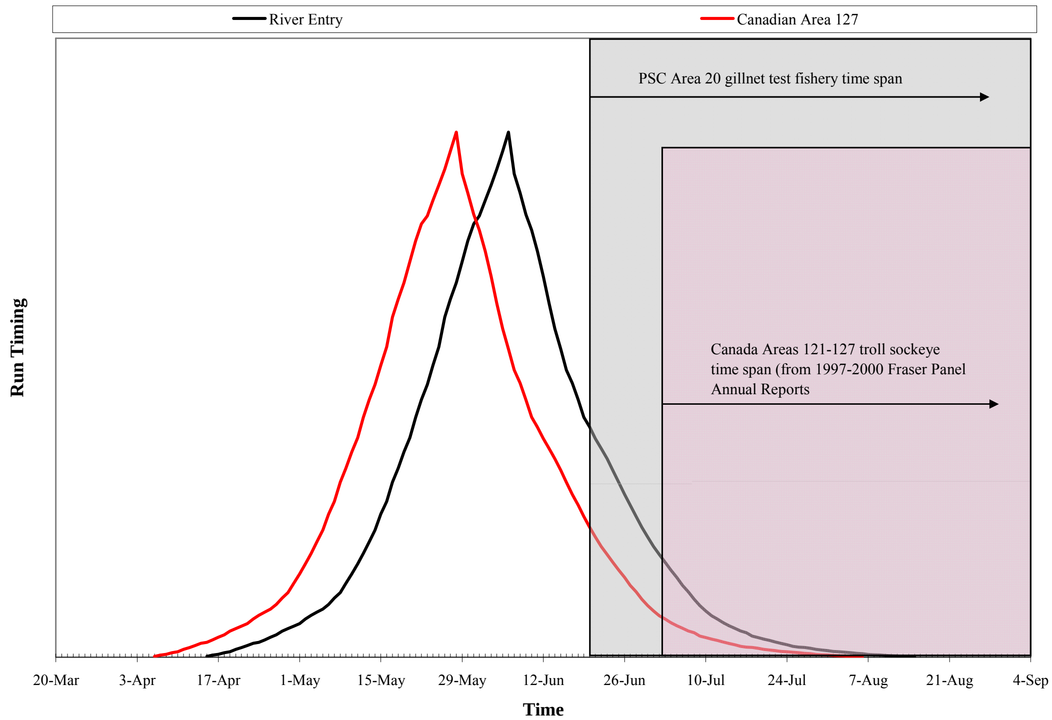

Figure 5.57. Estimated Lake Ozette sockeye WCVI migration timing compared with Canadian Areas 121-127 sockeye troll fisheries opening time span (1985-1995) and PSC Area 20 gillnet test fishery.

The Pacific Fishery Management Council ([PFMC] 2004) states that Council Area (southern U.S. coastal sport, commercial, and tribal fisheries) have no measurable impact on sockeye salmon. An additional review of recent (1995-2004) sport catch in coastal Washington fishing areas and Marine Areas 5 and 6 indicate that average sockeye catch is negligible. Partial time series sport catch data for these same areas from 1979 to 1994 further indicate that sport catch of sockeye salmon is negligible. Bycatch of sockeye in coastal whiting and bottom trawl fisheries also appears to be negligible, as few if any sockeye have been observed as bycatch.

5.6.2 Regional Sockeye Population Trends

In order to more fully understand potential mechanisms affecting Lake Ozette sockeye abundance at a scale larger than the Ozette watershed, time-series abundance data were compared to Lake Quinault sockeye abundance data to determine if similar trends in abundance are apparent between the two populations. Lake Quinault is located approximately 52 miles southwest of Lake Ozette, and is the closest sockeye population with long-term time series data on sockeye abundance. Lake Quinault sockeye exhibit several similar life-history strategies as Lake Ozette sockeye. Early run timing, protracted run timing, and long adult lake holding period before spawning (Gustafson et al. 1997) are key similarities between the two populations. Several dissimilarities between the populations also exist; for example Quinault sockeye are predominantly large river and tributary spawners (WDF et al. 1994). Recent abundance of Lake Quinault sockeye has been significantly reduced from historical abundance, similar to Ozette sockeye.

Lake Quinault sockeye run sizes averaged 234,212 from 1910 to 1956 (QIN, unpublished run size data). The last sockeye run greater than 200,000 adults occurred in 1956. From 1957 to 1975, the run size averaged 75,262 sockeye per year, representing an average run size reduction of 68%. From 1976-2004, the run size averaged 47,636 sockeye per year, representing an average run size reduction from the 1910-1956 period of 80%. The largest run size between 1910 and 2004 occurred in 1941 and was estimated to be 1,071,740 adult sockeye. The smallest adult return during this same time period occurred in 1999, when only 6,724 sockeye returned to Lake Quinault. The smallest return ever recorded was 0.6% of the highest return.

Run-size estimates for Lake Ozette sockeye are not available until the late 1970s. Harvest data are available from 1948 to present. Peak recorded harvest occurred in 1949, with 17,638 sockeye caught. Assuming 60% harvest rate results in an estimated run size of 29,396 sockeye in 1949. The smallest Lake Ozette sockeye run size estimate is for return year 1991, when 407 sockeye were estimated to enter the lake (assumes late run timing, estimate assuming mean 1998-03 run timing equals 1,520). The difference between the largest and smallest run size is approximately 1.3% using the estimates above. Recently the run size has averaged 3,600 sockeye (12% of highest abundance estimated from 1948 to present).

The abundance of both Quinault and Ozette sockeye have been significantly reduced from their historical numbers. Lake Quinault sockeye run sizes from 1996-2003 averaged 17% of the pre-1957 average run size. Ozette sockeye run sizes from 1996-2003 averaged 12% of the estimated peak abundance, which occurred in 1949. While the exact population reductions in both Lake Quinault and Lake Ozette sockeye will never be known, the estimates presented above are within the range of what could be reasonably expected. Interestingly, the estimated declines in Quinault and Ozette sockeye are within a very similar range. From 1957 to present neither of the populations has been able to produce a single return that approximates the size of returns observed prior to 1957.